REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	09-04-2012
2. REPORT TYPE	Final Report
3. DATES COVERED *(From - To)*	Jan 2008 - Apr 2012
4. TITLE AND SUBTITLE	Human Systems Integration Design Environment (HSIDE)
5a. CONTRACT NUMBER	N00014-08-C-0327
5b. GRANT NUMBER	
5c. PROGRAM ELEMENT NUMBER	
5d. PROJECT NUMBER	
5e. TASK NUMBER	
5f. WORK UNIT NUMBER	
6. AUTHOR(S)	Skrmetti, Thomas, J, Dr.
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	Rite-Solutions, Inc. 110 W. Broad St. Pawcatuck, CT 06379-1060
8. PERFORMING ORGANIZATION REPORT NUMBER	CY12-136
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	Office of Naval Research 875 N. Randolph St. Arlington, VA 22203-1995 Attn: Dr. William Krebs, ONR Code 342
10. SPONSOR/MONITOR'S ACRONYM(S)	ONR
11. SPONSOR/MONITOR'S REPORT NUMBER(S)	A007
12. DISTRIBUTION / AVAILABILITY STATEMENT	DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.
13. SUPPLEMENTARY NOTES	

14. ABSTRACT

The HSIDE prototype provides a single, easy to use, configuration-managed repository for the development and management of all HSI analyses, reports and resources. Users can assess and validate system designs and arrangements, generate analyses and manage their products all from a single, integrated environment. The integrated workflows link HSI analysts directly with the customer and other members of the design/build/sustain team. These capabilities should result in a noticeable improvement of the resulting designs and increased efficiency in the overall design process and the quality of the resulting HSI products.

15. SUBJECT TERMS

HSI, Manning Estimation and Validation, Risk Assessment, IPDE, PLM, BPMN, Workflow, Arrangement Optimization, Life Cycle Cost, Metrics

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(include area code)*
U	U	U	SAR	62	Dr. Thomas Skrmetti 860-599-1938 x195

HUMAN SYSTEMS INTEGRATION DESIGN ENVIRONMENT (HSIDE)

Project Report - Final

Contract No: N00014-08-C-0327
CLIN 0001
Data Item No. A007
April 9, 2012

Prepared for:

Dr. William Krebs
Program Manager, Capable Manpower
Office of Naval Research

Prepared by Rite-Solutions:

Dr. Thomas Skrmetti
CAPT David Olivier (USN, Ret)
ICC(SS) Mike Lame (USN, Ret)
Mr. Drew Jenkins
Mr. Jay Ferguson
Mr. Ian Mitchell
Mr. Jerry DeMasters
Ms. Sara Skrmetti
Mr. Brad Gaffney
Mr. Ed Way

Rite-Solutions

Contents

ACKNOWLEDGEMENTS: 3

SCIENTIFIC AND TECHNICAL OBJECTIVES 4

1 APPROACH 5

2 ACCOMPLISHMENTS 6

2.1 Refined user interface based on Phase I evaluation 7
2.1.1 Requirements 9
2.1.2 Process 9
2.1.3 Products, Scope and Status 11
2.1.4 High Driver Functions 13
2.1.5 Use Cases 14
2.1.6 Concepts and Designs 15
2.1.7 Analyses 16
2.1.8 Validation 16
2.1.9 Reports 17
2.1.10 Resources and References 17
2.1.11 User Interface Functionality Updates 17

2.2 Updated and expanded business process models 20

2.3 Developed method to support early identification of program risk and refined methods to define program scope and product set. 21
2.3.1 Risk Database 22
2.3.2 Risk Assessment to Program Scoping 25

2.4 Refined methodologies to support manning estimation and validation 27

2.5 Metrics 30

2.6 Developed Methodology to Optimize Team Arrangements 34
2.6.1 CONOPs 34
The subject content used was a hypothetical CONOPs for a command and control center developed under Rite-Solution's Combat System of the Future. Under this CONOPs, the following watchstations and duties were posited: 34
2.6.2 Communications Matrices 35
2.6.3 Optimization Routine 36
2.6.4 Results 38
3.6.5 VIRGINIA Class Example 42
2.6.5 Discussion 45

2.7 Completed Level A Technology Transition Agreement 46

2.8 Completed final prototype evaluation with Electric Boat 46
2.8.1 TTA Direction and Scope 46
2.8.2 Workflow Revisions 47
2.8.3 Evaluation Process 47
2.8.4 Evaluation Results 47
2.8.5 Supplemental Assessment 49

3 FINDINGS AND DISCUSSION 53

3.1 Lack of True System Engineering Perspective 53

3.2 Top Down Process versus Observed Execution 53

3.3 Legacy Systems / Push for Commonality 55

3.4 Manning for Design vs Design for Manning 55

3.5 Lack of Baseline Cost and Cost/Benefit Data to Support HSI Decisions in New Programs 56

3.6 HSI Functions Overlap those of Life Cycle Support 57

3.7 Recommendations 57
3.7.1 New Design Approaches 57
3.7.2 HSI Cost/Benefit Assessment 57
3.7.3 Expanded Systems Engineering Perspective 57

4 THE FUTURE OF HSIDE 59

5 REFERENCES 60

Acknowledgements:

The following General Dynamics Electric Boat team members participated in HSIDE development:

Tim Ahern	Kent Fields	Chris McMahon
Joe Bauer	Frank Florio	Charles Merlo
Paul Berlam	Dave Gallup	Rick Milnarik
Pat Bevins	Paul Gamwell	William Minor Jr.
Mike Bonin	Craig Haverly	Steve Missel
Joanne Casteel	Nate Kirmmse	Chad Pardo
Brett Cicchese	Tom Korzenowski	Larry Robbins
Dick Eddy	Jackie Krause	Karl Saila
Dave Eggler	Tom Kusnierz	Tom Smith
Ray Frenette	Ted Larson	Tim Taylor
Vic Fetter	Steve Libby	

A special note of recognition to:

Tanimu Deleon-Nwaha
Eric Jones
Bill Lyman
Steve Porter
Tom Scott
Don Slawski

In addition, the following organizations also participated in the Phase I effort:

Alion Science and Technology Corporation
General Dynamics, Bath Iron Works
Naval Undersea Warfare Center, Newport
Massachusetts Institute of Technology (Humans and Automation Laboratory)
Sonalysts, Inc.

Scientific and Technical Objectives

The original goal of the Human Systems Integration Design Environment (HSIDE) Program was to design, develop and evaluate a human-centered design environment and supporting processes. The objective was to provide a systems engineering approach to human systems integration in ship or submarine design. This involved the design, development and integration of an integrated HSI design process suitable for integration into a production design environment.

The resulting Human Systems Integration (HSI)-oriented design environment would integrate best of breed HSI tools and processes in a production, configuration-managed design system and incorporate extensive, automated simulation capabilities to support analysis and evaluation. This would allow system designers to rapidly define system requirements, construct alternative designs that satisfy those requirements and simulate and evaluate the various alternatives as to workload (cognitive and physical) and operability. Analyses and the associated HSI products would be configuration managed in the production configuration management system throughout the life of the program, ensuring product applicability across the life of the ship and minimizing life cycle development costs. The result would be a cost-effective ship design that is optimized for crew size, operability and military effectiveness.

Shortly after project start, Electric Boat decided to maintain Next-Generation IPDE development separate from HSIDE development. Therefore, a change in program scope was executed where HSIDE would be developed as a visual specification to aid Electric Boat HSI personnel in refining their requirements for the Next Generation IPDE. This change in scope was documented in the Phase I Report (Skrmetti, et al, 2010).

1 Approach

In phase I, the basic system elements and architecture were defined, tool evaluation studies were conducted and an initial set of metrics defined. A Phase I prototype system was developed and sample products were generated and integrated in the prototype environment to demonstrate potential use. Results of the Phase I efforts were described in the Phase I Report (Skrmetti, et al, 2010).

In Phase II, the existing prototype was to be refined based on the input from the Phase I evaluation. The Phase II prototype was to be evaluated by performing an analysis of the VIRGINIA Class manning plan, generating arrangement and operability studies to support the Combat System of the Future SBIR and shipboard Hull, Mechanical and Electrical (HM&E) systems. The final prototype design environment was to be assessed by Electric Boat engineers.

Based on the signing of the Level A TTA, the OHIO Replacement (OR) Program Office (PMS-397) and the Submarine Resource Sponsor (N87) requested that the scope of the prototype be focused on areas that would provide the most benefit for the program, namely increased design yard efficiency in the development of maintenance and Environmental Safety and Occupational Health (ESOH) products in support of the OR design effort. This is a change to the original program plan and scope and agreement is documented by the ONR Sponsor, N87 and the OHIO Replacement Program Office (PMS397) in a Level A TTA signed 18 April, 2011.

In addition to the work called out in the TTA, methodologies and tools were explored to support analysis of submarine manning and to optimize work area arrangements. Results are detailed in this report.

2 Accomplishments

As HSIDE development has proceeded through the last 4 years, the benefit of an integrated HSI design environment has become clear to both design yard and program office personnel. Previously, there was no integrated system to help execute or manage HSI work. Analyses were typically performed outside of the core system engineering efforts and the scope of coverage was restricted by program requirements. In addition, management of some completed studies was informal and, in some cases, the studies were inaccessible to others.

The HSIDE prototype provides a single, easy to use, configuration-managed repository for the development and management of all HSI analyses, reports and resources. Users can assess and validate system designs and arrangements, generate analyses and manage their products all from a single, integrated environment. The integrated workflows developed over the last few years link HSI analysts directly with the customer and other members of the design/build/sustain team. These capabilities should result in a noticeable improvement of the resulting designs and increased efficiency in the overall design process and the quality of the resulting HSI products.

In addition to the design and development of the underlying HSIDE Infrastructure, several new tools and methodologies were developed to assist analysts in future work. These include: a linear programming model to estimate manning requirements; an optimization function that relates Concept of Operations (CONOPs) to communications requirements to optimized arrangements; a watchstander modeling tool that allows rapid generation of recommended manning plans and crew cost estimates for new or modified ships or CONOPs; a risk assessment methodology to allow program managers to quickly estimate HSI risk at the ship and system level; and methodology to rapidly define and manage the scope of an HSI program through the life cycle of the ship.

Specific details of work accomplished during Phase I of HSIDE were previously reported in Skrmetti, et al, 2010. The following major work was accomplished during Phase II:

1. Refined system architecture and user interface based on Phase I evaluation.
2. Updated and expanded business process models and workflows to reflect design yard SME input following initial prototype assessment.
3. Developed method to support early identification of program risk and refined methods to define program scope and product set.
4. Refined methodologies to support manning estimation and validation.
5. Developed a set of design yard utility metrics to assess the impact of HSIDE-like processes on ship design.

6. Developed a linear programming model to optimize arrangement of control room watchstanders.

7. Completed Level A Technology Transition Agreement between ONR, N87 and PMS397.

8. Competed final prototype evaluation with Electric Boat

A detailed description of Phase II accomplishments is provided below.

In addition to the specific technical accomplishments, HSIDE has acted as a catalyst for Electric Boat to reorganize their HSI efforts and organization. HSI processes were defined, documented and formalized and integrated in the Design/Build/Sustain team approach. HSI personnel were consolidated under a single director and roles and responsibilities differentiated from that of traditional Life Cycle Support. In general, participation in the HSIDE program increased Electric Boat's awareness, and appreciation, of the benefits that can be accrued through the systematic application of human systems integration in a new design.

2.1 Refined user interface based on Phase I evaluation

The basic user interface is a web-based front end that is linked to a back end Product Life Cycle Manager (PLM). The web-based interface is a functionally-oriented user interface that reflects the structural components of an HSI program. The PLM provides services such as product structuring, workflow and configuration management. PLMs are complex systems that require a great deal of training to use efficiently and typically only a few people in an organization are able to fully exploit the power of a PLM. Integrating a functionally-oriented, web-based front end with a complex PLM allows users to harness the power of the PLM without having to deal with the underlying complexity.

In typical design environments, users are faced with navigating through a tremendous amount of data to effectively utilize the system. Under the program organization, 2 complimentary sets of filters have been implemented to assist the user in filtering through the large amounts of available data and quickly zero in on the specific data of interest. The first set of filters are set up to reflect the structure of the Navy Extended Ships Work Breakdown Structure (ESWBS) to facilitate efficient user navigation through a large amount of data, organized by Program, Hull, Area, System and Component categories. The filter portion of the user interface is shown in Figure 1.

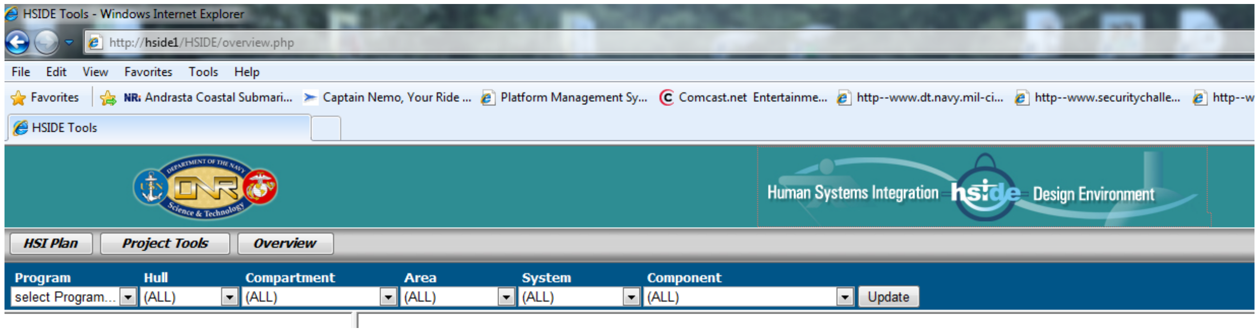


Figure 1: Filter Selections in User Interface

The other filtering scheme involves filtering information via a functional breakdown of the major HSI areas including human engineering, manpower, personnel and training, habitability, environmental safety and occupational health (ESOH) and survivability. Sub functions (operability and maintainability, work area arrangements and work station design) are organized under human engineering.

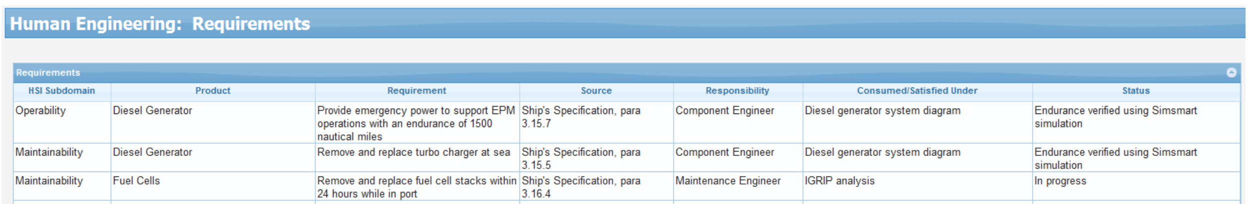
The user interface design has been modified to reflect a basic level of standardization across all HSI functional areas. The basic choices under each functional area are now standardized as follows:

a. Requirements
b. Process
c. Products, Scope and Status
d. High Driver Functions
e. Use Cases
f. Concepts And Design
g. Analysis
h. Validation
i. Reports
j. Resources and References

By using the 2 sets of filters, an analyst or manager is able to quickly and efficiently drill down to the specific information and products they are seeking to support their analyses or review. A full description of each of these major areas is provided in the following text.

2.1.1 **Requirements**

Under this choice, the user is directed to a requirements database that contains all of the known base and derived requirements associated with the particular HSI area and for the program, ship (hull), area, system or component. The intent is to ultimately link this selection to a production requirements database (e.g., DOORS or a functionally similar system). Currently, the linkage is to a systems database that emulates the basic expected capabilities. Figure 2 shows a filtered excerpt from the Requirements database.


Human Engineering: Requirements

Requirements

HSI Subdomain	Product	Requirement	Source	Responsibility	Consumed/Satisfied Under	Status
Operability	Diesel Generator	Provide emergency power to support EPM operations with an endurance of 1500 nautical miles	Ship's Specification, para 3.15.7	Component Engineer	Diesel generator system diagram	Endurance verified using Simsmart simulation
Maintainability	Diesel Generator	Remove and replace turbo charger at sea	Ship's Specification, para 3.15.5	Component Engineer	Diesel generator system diagram	Endurance verified using Simsmart simulation
Maintainability	Fuel Cells	Remove and replace fuel cell stacks within 24 hours while in port	Ship's Specification, para 3.16.4	Maintenance Engineer	IGRIP analysis	In progress

Figure 2: Filtered Requirements Set

2.1.2 **Process**

Under this selection, the user is presented with a choice to view either the business process model in Business Process Modeling Notation (BPMN) or the actual workflow template associated with the specific functional area, again as filtered by the user settings in the high level interface. Figure 3 shows the initial screen which allows the user to select either the BPMN or the actual workflow template.

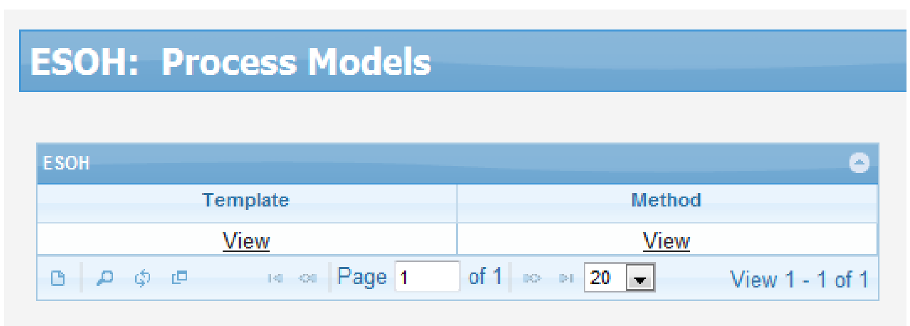


Figure 3: Process Selection Sub Menu

A representative BPMN (partial) is shown in Figure 4.

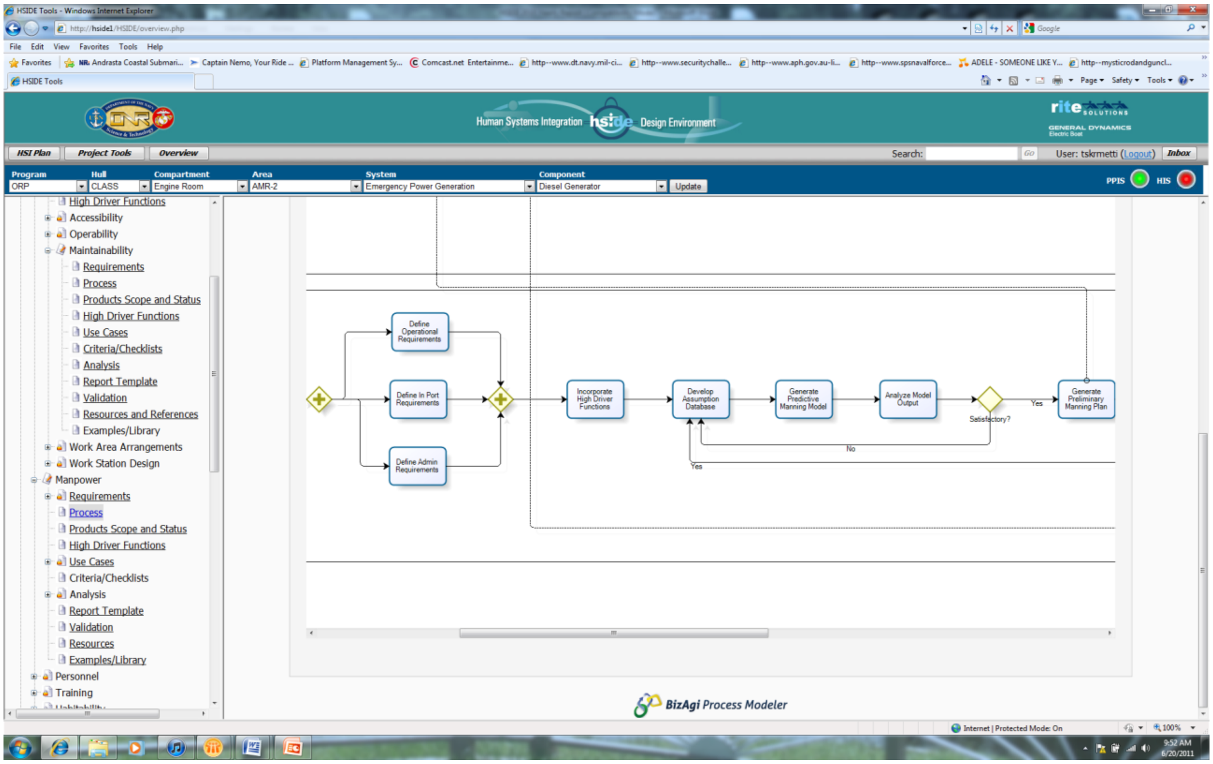


Figure 4: Representative BPMN (Partial)

Figure 5 shows a representative workflow template for ESOH.

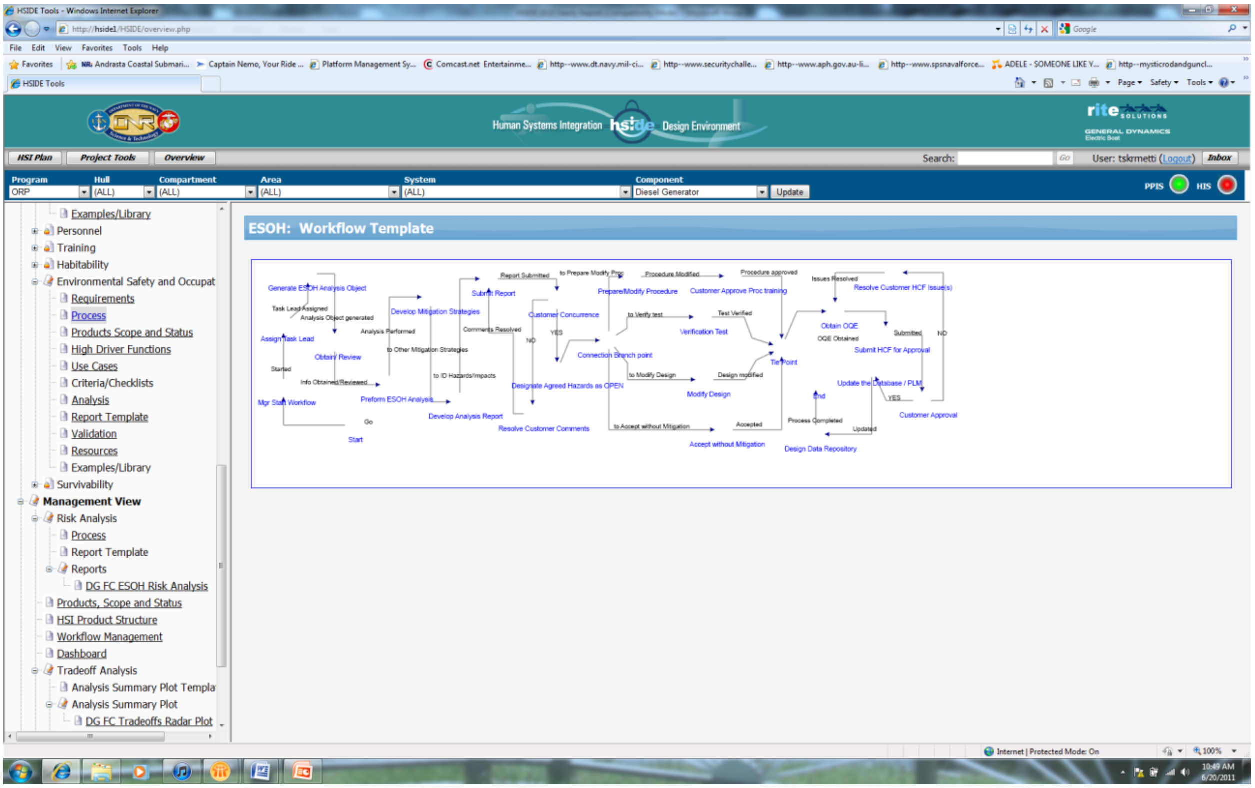


Figure 5: ESOH Template

2.1.3 Products, Scope and Status

Under this selection, the user is presented with a list of the applicable workflows, filtered by functional area and specific ship WBS selections as shown in Figure 6.

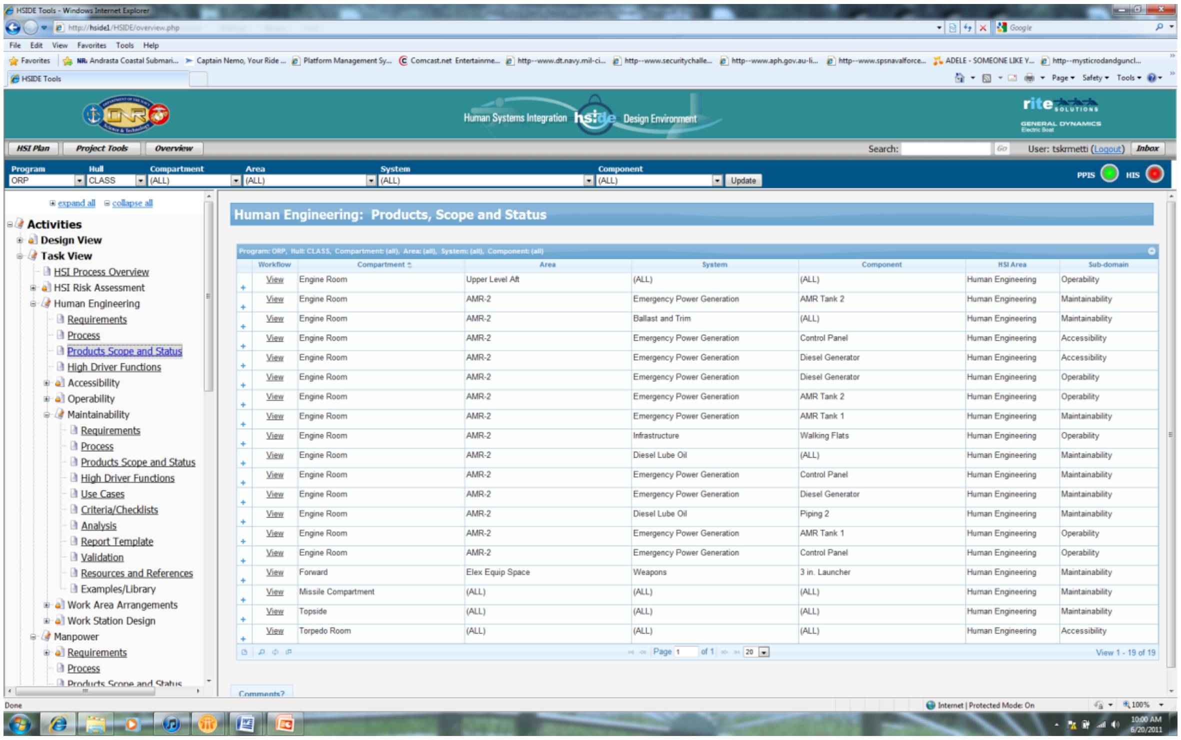
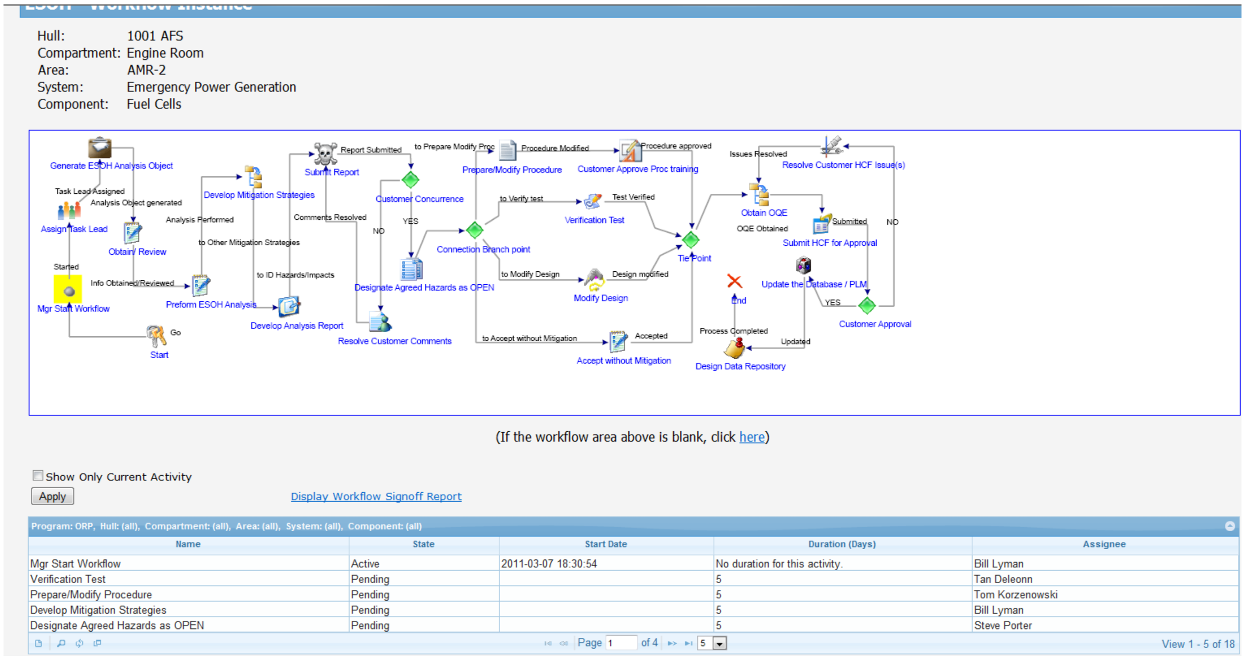


Figure 6: Products, Scope and Status Selection

When the user selects “View” for the product of interest, they are presented with a visual representation of the applicable workflow instance. The specific step in the workflow is highlighted in Yellow and the supplemental information for each activity, including status, start date and assignee, is listed in a table at the bottom of the web page. Figure 7 shows a specific ESOH workflow and supplemental data associated with an analysis for emergency power generation.



Name	State	Start Date	Duration (Days)	Assignee
Mgr Start Workflow	Active	2011-03-07 18:30:54	No duration for this activity.	Bill Lyman
Verification Test	Pending		5	Tan Deleonn
Prepare/Modify Procedure	Pending		5	Tom Korzenowski
Develop Mitigation Strategies	Pending		5	Bill Lyman
Designate Agreed Hazards as OPEN	Pending		5	Steve Porter

Figure 7: Product Workflow Graphic and Supplemental Data

2.1.4 High Driver Functions

The High Driver Functions selection takes the user to a filtered set of database entries that summarize the major problems associated with a specific area, system or component. The database was developed under HSIDE as there are currently no fleet wide data systems that integrate and organize problem information for use in follow on designs. The High Driver Database was developed to allow users to input known problems, using a bottoms up approach and to generate a maintainable database that can be used through the design phase and updated throughout the life cycle. This allows a running record of problems that need to be addressed in either upgrades to the current design or in new program starts to be maintained. Figure 8 shows a set of filtered database entries for the High Driver Functions.

ESOH: High Driver Functions

High Driver Functions

System Component	Risk Category	Risk	Remediation	Analysis Responsibility	Remediation Status	Remediation Responsibility	Comments
HP Brine Pump	Environment	High Ambient Noise Levels	Sound-Insulated Enclosure (e.g., Gas Turbines)	HSI	Complete	Systems Design	Sound enclosure incorporated in component specification
HP Brine Pump	Environment	High Ambient Temperature Levels	AC	HSI	Complete	Systems Design	Accept As Is
HP Brine Pump	Environment	High Ambient Vibration Levels	Improved Isolation	HSI	Complete	Systems Design	Mounts revised on foundation model
HP Brine Pump	Hazards	Exposed Rotating Machinery	Physical Guards	HSI	Complete	Complete s Design	Guards incorporated in component specification
HP Brine Pump	Hazards	Flooding Hazard	Interlocks / Training / Maintenance / Certification / Monitoring	HSI	Complete	Systems Design	Interlocks included in control circuitry
HP Brine Pump	Hazards	High Temperature Exposed Components	Thermal Insulation / Heat Pipes	HSI	Complete	Systems Design	Insulation incorporated in system specification
Diesel Generator	Environment	High Ambient Noise Levels	Sound-Insulated Enclosure (e.g., Gas Turbines)	HSI	Working	Design / Build Team	
Diesel Generator	Environment	High Ambient Temperature Levels	AC	HSI	Working	Design / Build Team	
Diesel Generator	Environment	High Ambient Vibration Levels	Improved Isolation	HSI	Complete	Systems Design	Mounts revised on foundation model
Diesel Generator	Hazards	Atmospheric - CO / CO2 Leakage	Monitoring	HSI	Complete	Systems Design	Constant CO2 Monitor Incorporated
Diesel Generator	Hazards	Exposed Rotating Machinery	Physical Guards	HSI	Working	Arrangements Design	
Diesel Generator	Hazards	Flooding Hazard	Interlocks / Training	HSI	Complete	Systems Design	Interlock Incorporated in Ckt 1SN
Diesel Generator	Hazards	High Temperature Exposed Components	Thermal Insulation / Heat Pipes	HSI	Complete	Systems Design	Insulation incorporated in system specification
Diesel Generator	Hazards	High Vacuum in Ship	Interlocks /	HSI	Complete	Systems Design	Interlock Incorporated in Ckt 1SN

Figure 8: High Driver Database Functions

2.1.5 Use Cases

The HSIDE team has standardized the use of Unified Model Language (UML) Modeling to analyze existing operating procedures and methods and to model proposed operating methods. The resulting models are used to analyze and document watchstander requirements, performance times, and to identify user interface and communications requirements.

UML sequence diagrams focus on documenting the behavior within a system by visually modeling the flow of logic. Sequence diagrams are used to both validate the logic and to support process analysis. Activity diagrams are graphical representations of the overall flow of control in a process. They describe the business and operational step-by-step workflows of components in a system. Figure 9 shows a portion of typical sequence diagram.

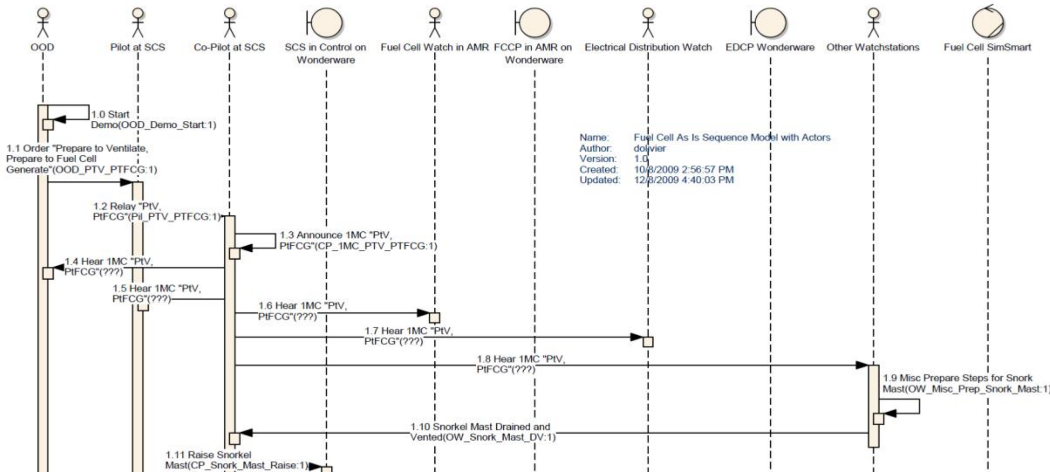


Figure 9: Portion of a Typical Sequence Diagram

Figure 10 shows an excerpt from a typical activity diagram.

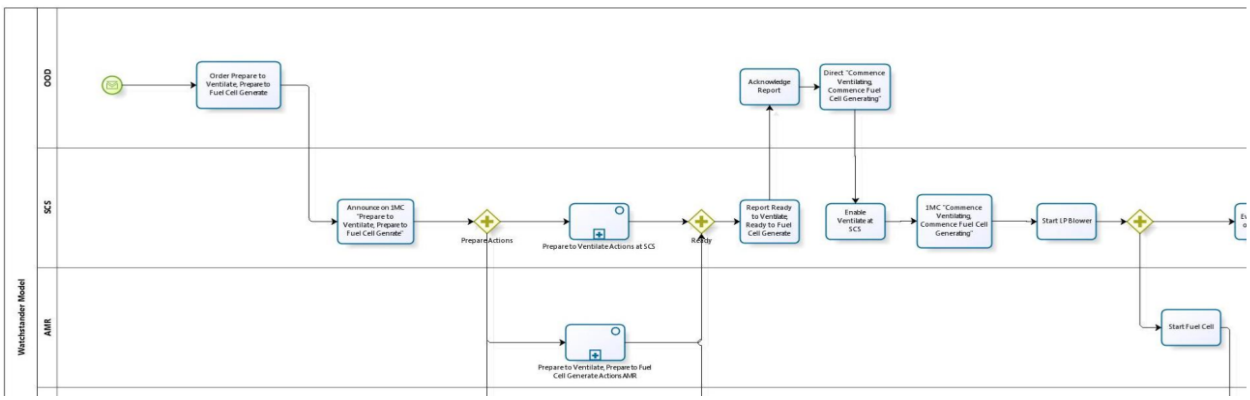


Figure 10: Activity Model Excerpt

2.1.6 Concepts and Designs

This selection allows a user to select a filtered list of concepts focused on their immediate area of interest. Concepts can take many forms, including text descriptions, PowerPoint studies, 2D graphics and 3D studies and arrangement models. Figure 11 illustrates a typical concept model used to assess the arrangement of a notional Command and Control Center (CACC).

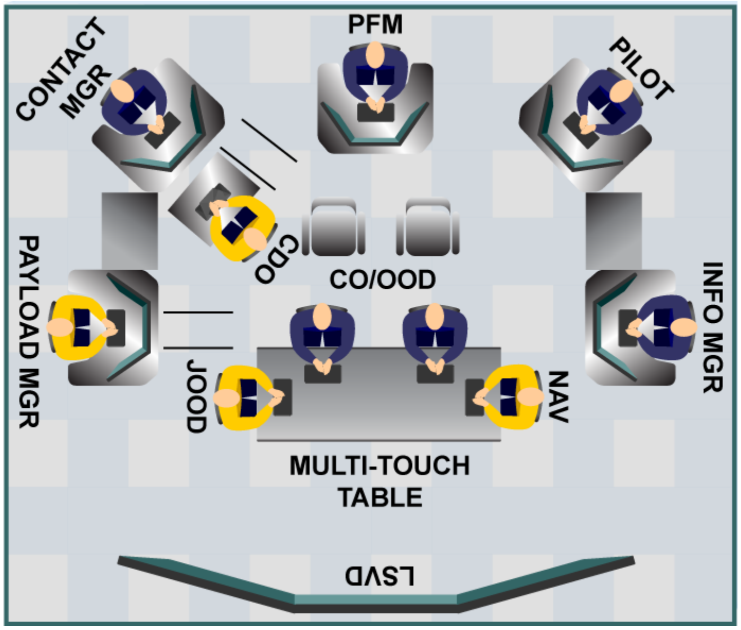
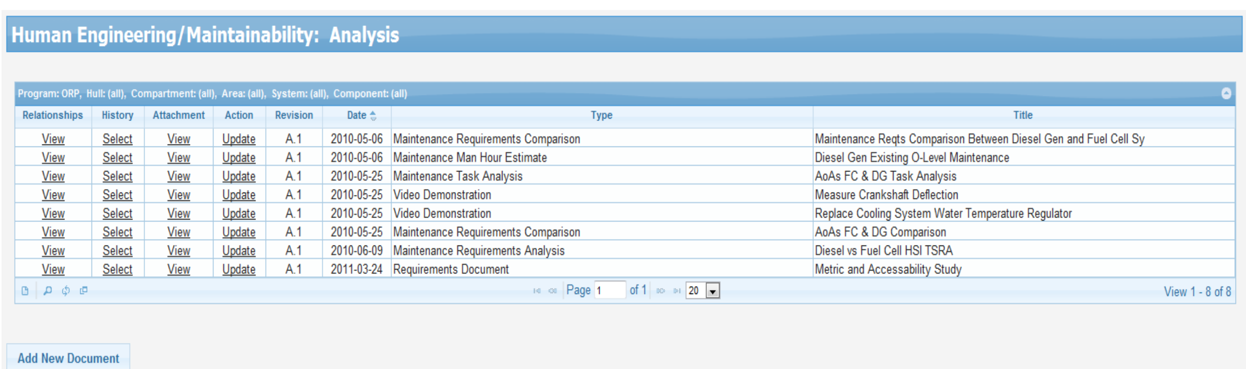


Figure 11: Notional CACC Arrangement Concept

2.1.7 **Analysis**

The Analysis selection allows a user to select filtered list of analyses focused on their immediate area of interest or to add a new document to the list. Figure 12 shows the user interface associated with viewing and adding analyses to the system.



Relationships	History	Attachment	Action	Revision	Date	Type	Title
View	Select	View	Update	A.1	2010-05-06	Maintenance Requirements Comparison	Maintenance Reqts Comparison Between Diesel Gen and Fuel Cell Sy
View	Select	View	Update	A.1	2010-05-06	Maintenance Man Hour Estimate	Diesel Gen Existing O-Level Maintenance
View	Select	View	Update	A.1	2010-05-25	Maintenance Task Analysis	AoAs FC & DG Task Analysis
View	Select	View	Update	A.1	2010-05-25	Video Demonstration	Measure Crankshaft Deflection
View	Select	View	Update	A.1	2010-05-25	Video Demonstration	Replace Cooling System Water Temperature Regulator
View	Select	View	Update	A.1	2010-05-25	Maintenance Requirements Comparison	AoAs FC & DG Comparison
View	Select	View	Update	A.1	2010-06-09	Maintenance Requirements Analysis	Diesel vs Fuel Cell HSI TSRA
View	Select	View	Update	A.1	2011-03-24	Requirements Document	Metric and Accessability Study

Figure 12: Filtered Analysis Query Results

2.1.8 **Validation**

The Validation selection allows a user to generate and view the objective quality evidence associated with the assessment of a given HSI product. The intent is to provide a template to the users that can be filled in and added as an HSI product to the product data set. There are 2 types of validation currently in the system. The first is a set of human engineering checklists developed by Electric Boat on the VIRGINIA Class. The second is a set of database tables that are modeled on the NAVSEA05H System Engineering Technical Requirements (SETR) Criteria for Ship Systems. Users can fill in

the appropriate information, add their name and date and save the information as a separate design validation document associated with the specific area, system or component of interest. Figure 13 shows the results from a typical database query for a System Requirements Review.

Human Engineering/Maintainability: Validation

Validation

Review	Requirement	Verified By	Date
SRR	MAI SRR1 Manual handling required during maintence complies with established manual force criteria.		
SRR	MAI SRR2 Special tools for operational adjustment maintenance have been securely mounted within or near the equipment in a readibly accessible location.		
SRR	MAI SRR3 It ispossible to check and adjust each item , or the function of an item, individually.		
SRR	MAI SRR4 Equ[MAI SRR3 It ispossible to check and adjust each item , or the function of an item, individually.]ection and isolation of defective items to permit their prompt removal and replacement.		
SRR	MAI SRR5 Equ[illegible]nbled in its operational environment by a minimum number of trained personnel wearing clothing appropriate to the operating environment in accordance with the given maintenance concept.		
SRR	MAI SRR6 Equipment is capable of removed, replaced and repaired by personnel wearing personal and special purpose clothing and using equipment appropriate to the given maintenance concept.		
SRR	MAI SRR 7 Modular or unit packaging has been used, designed for rapid and easy removal by one person		
SRR	MAI SRR8 Self-lubricating technology has been used to the maximum extent possible and exceptions noted.		
SRR	MAI SRR9 Components and assemblies are sealed and prelubricated .		
SRR	MAI SRR10 Built in testing and calibration features have been incorporated for major components		
SRR	MAI SRR11 Self adjusting mechanisms have been incorporated into the design.		
SRR	MAI SRR12 Gear driven accessories have been utilized to eliminate belts and pulleys.		
SRR	MAI SRR13 Number and complexity of maintenance tasks have been mimized - documented in trade off analaysis		
SRR	MAI SRR14 Skill and training requirements equired for maintenance personnel have been minimized and are documented in a trade off study		
SRR	MAI SRR14 Safety and protection for personnel and equipment has been maximized.		
SRR	MAI SRR15 Standard parts have been to the maximum extent feasible and any exceptions documented		
SRR	MAI SRR16 Manual handling required during maintence complies with established manual force criteria.		

Page 1 of 1 20 View 1 - 17 of 17

Figure 13: Typical SETR Database Query

2.1.9 **Reports**

This selection allows a user to access existing reports as filtered by the selection criteria. Sub-headings are provided for the user to access an approved set of templates for specific report types which can then be saved to the user's desktop. After the report has been completed, it can be uploaded into the product structure as described in Section 1.2.2.

2.1.10 **Resources and References**

This selection allows the user to view and select a list of references and related resources for the specific subject matter they are interested in as defined by the standard selection criteria. Figure 14 shows a filtered list of resources and references for the maintainability function.

Human Engineering/Maintainability: Resources

Resources

Product	Reference	Attachment
Diesel Generator	Ship's Specifications	N/A
Fuel Cells	Ship's Specifications	N/A
TDU	Ship's Specifications	N/A
Diesel Generator	MRC-C3 E1GSY	View
Diesel Generator	MRC-C6 E1GRN	View

Page 1 of 1 20 View 1 - 5 of 5

Figure 14: Filtered Example of Resources and References

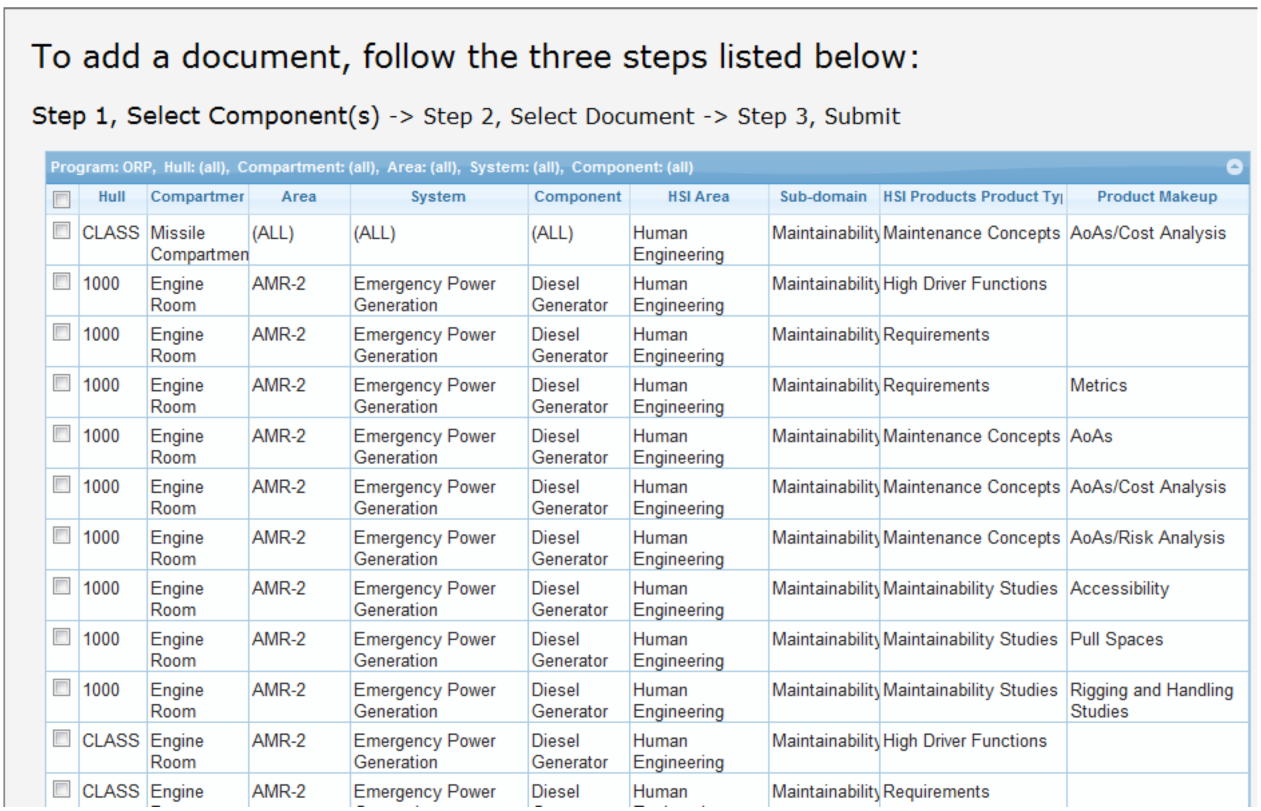
2.1.11 **User Interface Functionality Updates**

As noted in the Phase I Report, the heart of the HSIDE environment is a Product Life Cycle Management (PLM) system. These systems are very powerful but require a great deal of expertise to use efficiently. The HSIDE team has designed and developed a web-based, functional interface for the end user that allows them to harness the power of the PLM without requiring a steep learning curve. As the HSIDE interface continued to evolve, new functionality

was added to make it easy for the end users to add information into, and extract information from, the PLM database. Two major new functionalities, the ability to add new products into the system and the ability to define relationships and dependencies for HSI products, have been developed and are described below.

2.1.11.1 Ability to add new products into the system

This screen provides the user with the ability to add new products into the system. The end user selects the appropriate filter set and is provided with a list of potential product types. After the specific product type is selected, they are then provided with a standard file browser that allows them to select and upload a given file (product) into the system. Figure 15 shows a typical product type selection window. The user simply clicks the check box associated with the specific product type (associated with the selected filter criteria) they want to add to the system.


To add a document, follow the three steps listed below:

Step 1, Select Component(s) -> Step 2, Select Document -> Step 3, Submit

Program: ORP, Hull: (all), Compartment: (all), Area: (all), System: (all), Component: (all)

	Hull	Compartmen	Area	System	Component	HSI Area	Sub-domain	HSI Products Product Ty	Product Makeup
	CLASS	Missile Compartmen	(ALL)	(ALL)	(ALL)	Human Engineering	Maintainability	Maintenance Concepts	AoAs/Cost Analysis
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	High Driver Functions	
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Requirements	
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Requirements	Metrics
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintenance Concepts	AoAs
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintenance Concepts	AoAs/Cost Analysis
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintenance Concepts	AoAs/Risk Analysis
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintainability Studies	Accessibility
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintainability Studies	Pull Spaces
	1000	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	Maintainability Studies	Rigging and Handling Studies
	CLASS	Engine Room	AMR-2	Emergency Power Generation	Diesel Generator	Human Engineering	Maintainability	High Driver Functions	
	CLASS	Engine	AMR-2	Emergency Power	Diesel	Human	Maintainability	Requirements	

Figure 15: Typical Product Selection Window

After the user has selected the desired product type, a standard file browser window allows them to select the desired file (product) and upload it into the PLM database without the need for the user to directly interact with the PLM. Figure 16 shows a typical file browser and selection window.

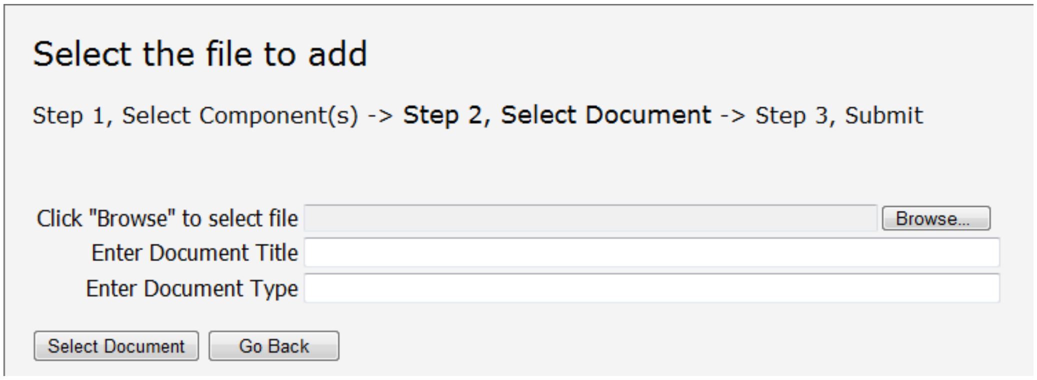


Figure 16: Typical File Browser and Selection Window

2.1.11.2 Ability to define relationships and dependencies for HSI products

One of the major capabilities utilized in HSIDE is the PLM's ability to configuration manage parts assemblies. HSIDE uses this ability to configuration manage the relationships between products and the resources on which they were based. Again, the arcane, parts-based user interface usually associated with a PLM has been hidden from the end user and a simple mechanism has been developed to allow them to easily define these relationships. This allows the PLM to automatically notify the end user whenever a source product has been modified which could result in an impact to an existing HSI product.

Figure 17 shows the interface screen that lists the current dependencies and where the end user is able to initiate the process to define a new dependency. The user simply clicks on the button at the bottom of the screen to select a new document and the system will open a standard file browser window. The user simply selects the file they want to flag as a source document and the PLM will automatically establish and manage the required relationship.

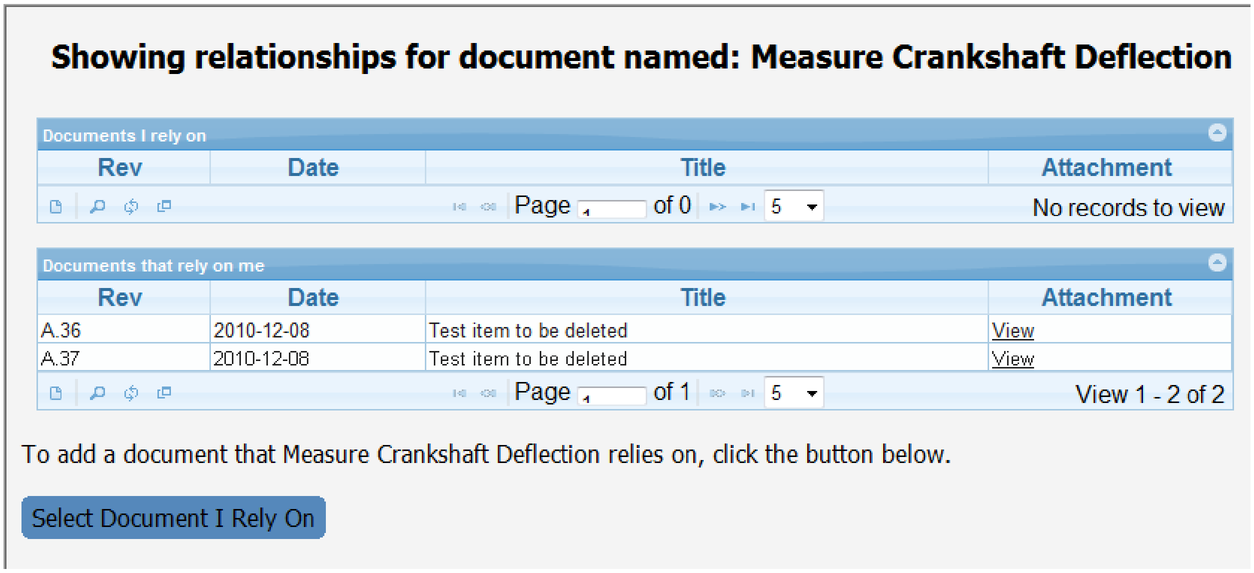


Figure 17: Relationship Display and Definition Screen

Figure 18 shows the file browser window that the user will use to define the dependency relationship.

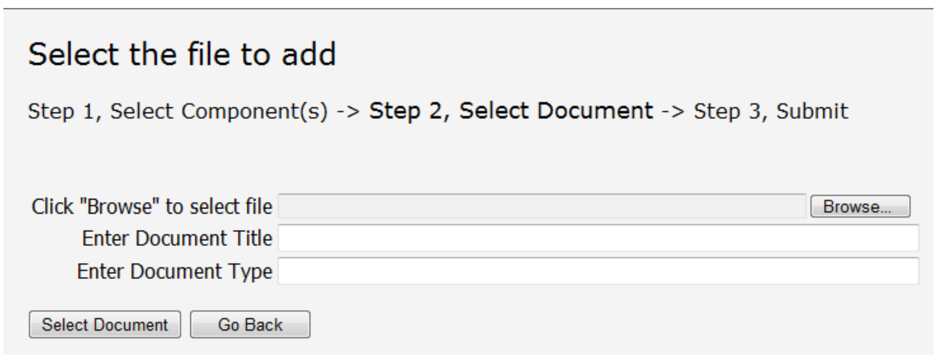


Figure 18: File Browser Window

2.2 Updated and expanded business process models

The business process models have been expanded and refined based on user comments during the initial evaluation. In addition, attachments have been added to each major product or supporting document showing either representative products or the actual supporting documents for the given activity. Figure 19 shows the menu associated with the Biz Agi BPMN tool that allows an end user to access the associated attachment. When selected, the attachment is automatically opened in the appropriate application using normal Windows file access.

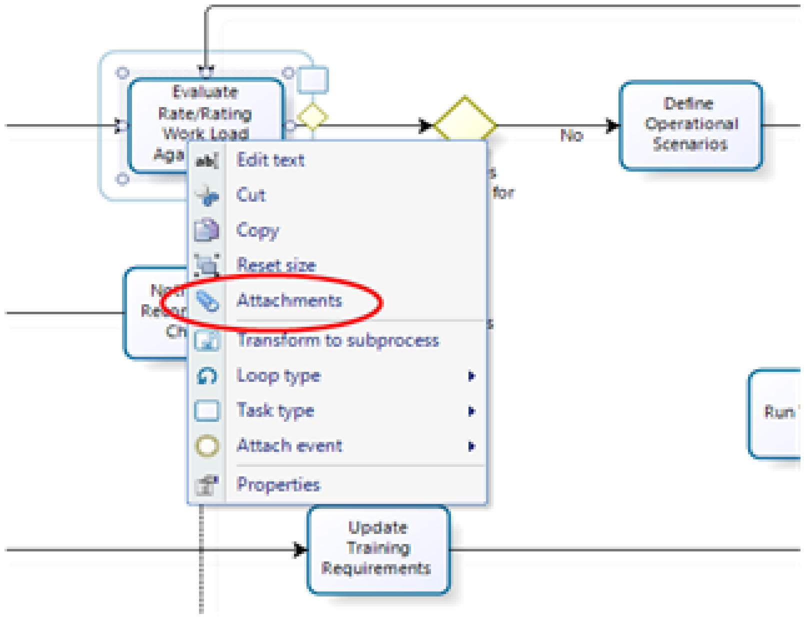


Figure 19: Biz Agi Menu Screen to Access BPMN Activity Attachments

2.3 Developed method to support early identification of program risk and refined methods to define program scope and product set

An area of utmost importance at the start of a new program is to identify the "amount" of HSI activity that is planned to take place. Although an ideal program would perform a full suite of HSI analyses for all compartments and equipment sets, budget and schedule constraints require that an optimal level of effort be defined that maximizes HSI utility to the program while minimizing the required resources.

In addition, due to budget pressures and the desire for commonality to reduce life cycle costs, there is always a push for reuse of legacy systems that further complicates the issue and moves the program further from an ideal HSI situation. This decision requires a quantitative assessment of the risk associated with the different elements of the program and, currently, there are no easy to use tools to help a manager determine their HSI risk level.

Figure 20 shows the overall process that allows a user to define program HSI risk, translate that risk to a program scope, estimate the program cost, negotiate a final program scope and manage and execute the resulting program. Note that the module associated with generating a program ROM are still in development.

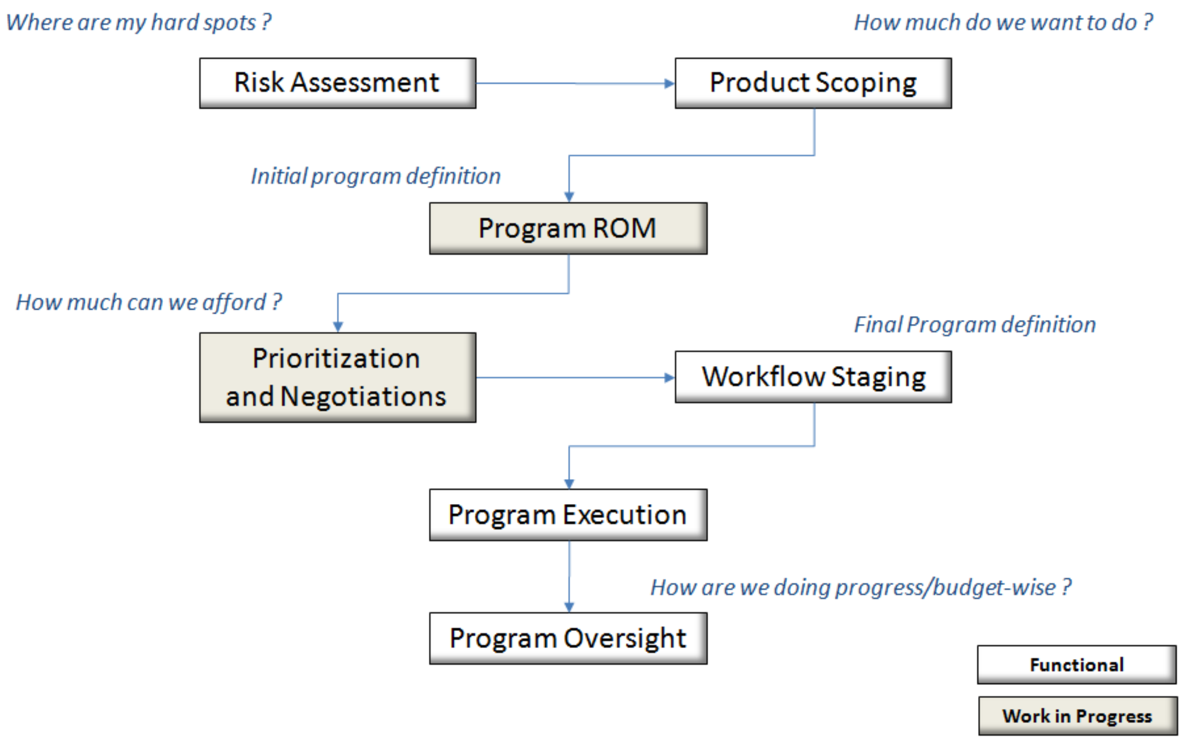


Figure 20: Integrated Risk Assessment and program Scope and Execution

2.3.1 Risk Database

The HSIDE team has developed a set of 3 components and associated functions that allow a manager to quickly define, quantify and assess the HSI risks associated with a given program. The risks can be assessed at the ship, compartment or system level.

The first component is a checklist used to assess risk at the program level. A set of questions and functions have been developed to generate a quantitative assessment of the level of risk associated with an overall program. The checklist is broken down along the functional HSI areas: manpower, personnel, training, habitability, etc. A set of questions are associated with each given area. These questions are weighted and normalized. The user can adjust the weights as desired as long as the sum of the weights for any given area continue to add up to 1.0, as enforced by the algorithm. Each question is assumed to have a value of 1 times the weighting factor. As an example, under the Habitability function, a question is asked about whether or not accommodations have been made for women in the areas of sanitation and berthing. A weighting factor of 0.33 has been assigned to the question. If the answer is "Yes," a total contribution of 0.33 (1 x 0.33) is added to the score. The sum of the values for each area is then summed and a percentage is calculated of the actual scores divided by the possible scores. The lower the score, the higher the level of risk. Figure 21 shows an example of the shipwide assessment.

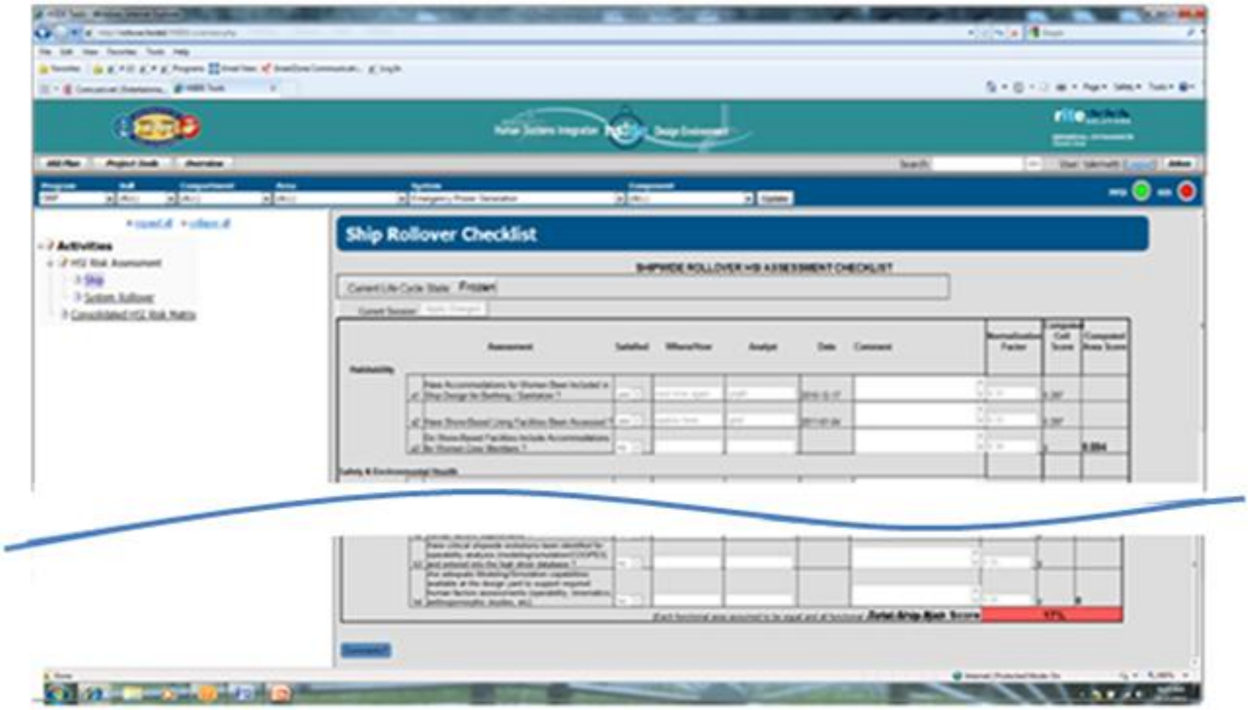


Figure 21: Shipwide Risk Assessment

The second set of components are associated with ship systems. The requirement to rollover legacy systems into a new design can introduce constraints on a top down HSI program. It can also, however, reduce risk if substantial amounts of HSI analysis have already been performed.

To help program managers assess the risk associated with the system level, a series of questions have been generated that are used to assess a system in each of the major HSI functional areas. These questions are weighted and normalized. The user can adjust the weights as desired as long as the sum of the weights for any given area continue to add up to 1.0. An additional field has been added to reflect the level of criticality of the system and the scoring is identical to that described above for the program level. Figure 22 shows an example of the system level (rollover) risk assessment.

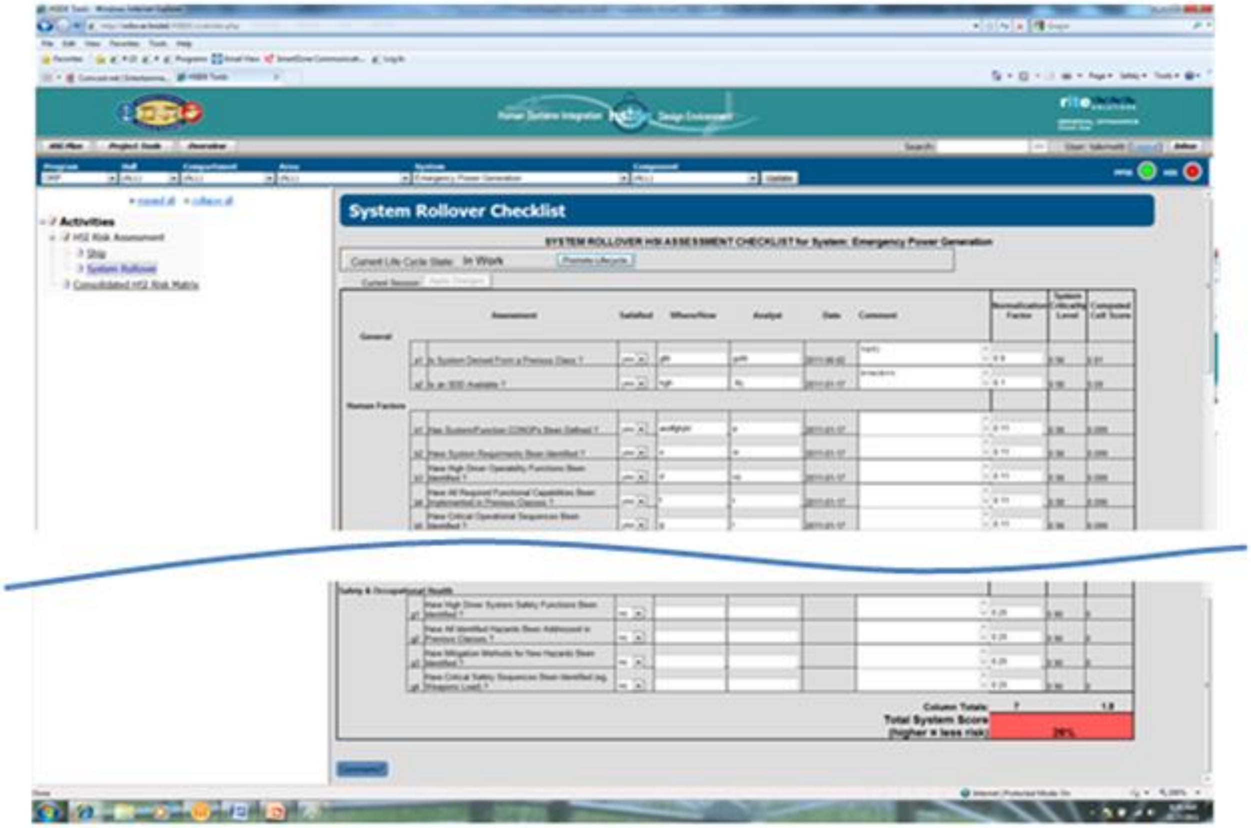


Figure 22: System (Rollover) Assessment

The third component is a rollup of the individual system scores. This allows easy comparison of system composite scores so a manager can easily identify potential problems areas. The individual system scores are multiplied by the level of criticality for the given system to generate a composite score. Each composite score is automatically assessed using a threshold defined by the end user and the resulting scores are color coded green, yellow or red, depending on how it compares to the specific threshold values. The lower the score, the higher the level of risk. Figure 23 shows an example of a consolidated system risk matrix.

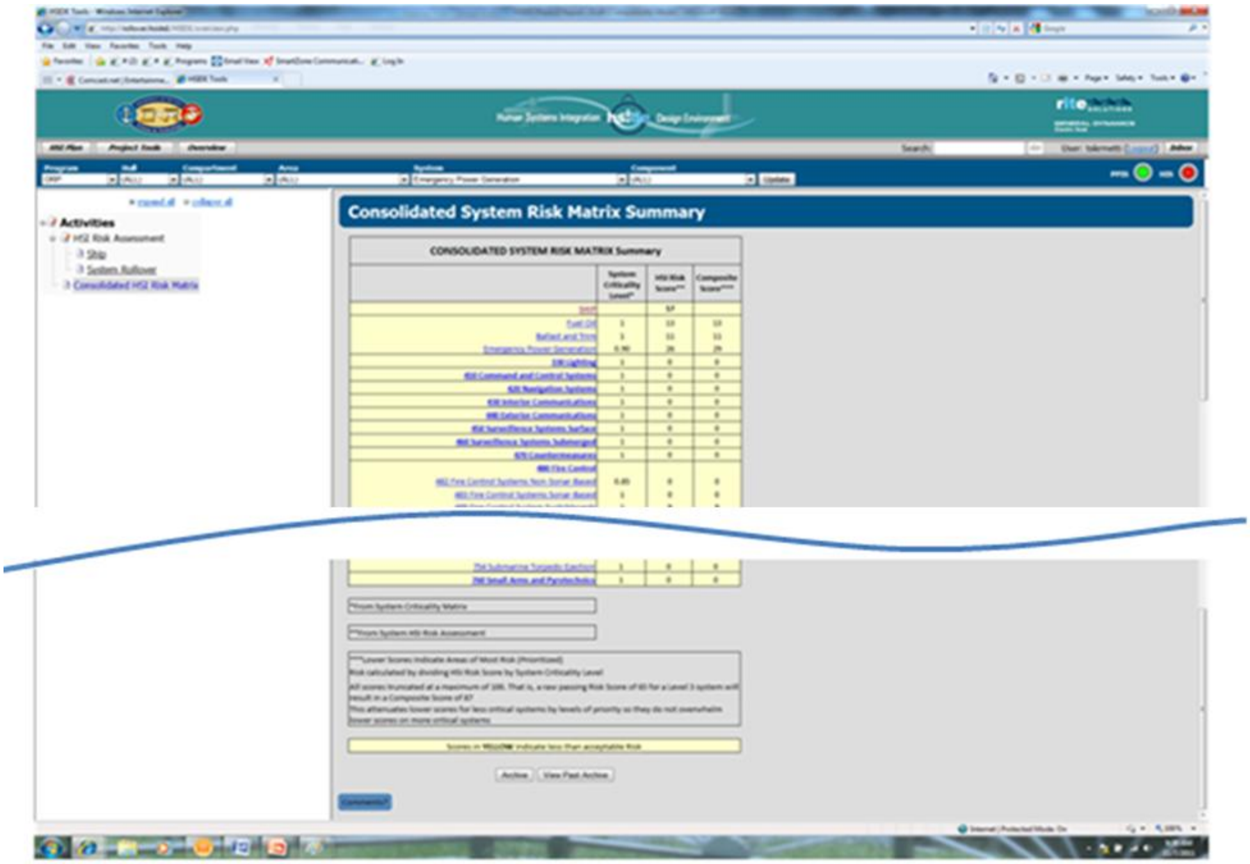


Figure 23: Consolidated System Risk Matrix

Together, these 3 components allow a program manager to rapidly assess the state of a program and determine where the most resources should be targeted. Since the components have all been developed in database form. it is a simple matter for a program manager to refine, add or delete questions to tailor them to suit a specific program. In addition, the weighting factors may also be manipulated by the user to reflect program priorities with the system constraining the normalization factors to ensure unity for each functional area.

2.3.2 Risk Assessment to Program Scoping

Following the risk assessment, program managers can use the output of the Risk Assessment process to input data into the HSIDE product structure. This function is laid out in an identical manner to the risk database and reflects the Extended Ship's Work Breakdown Structure (ESWBS) on one axis and HSI functional areas on the other. By simply clicking in the intersection of ESWBS item and HSI functional area, the manager establishes an entry into the HSI product structure and stages a workflow for that system, component and functional area. As an example, in Figure 24, the manager has clicked on the Torpedo Room and the Maintainability function. A new HSI product structure entry will be generated in the PLM against the Torpedo Room for a maintainability analysis and a maintainability workflow for the Torpedo Room will be

generated by the PLM and shown under Product, Scope and Status in the Management View.

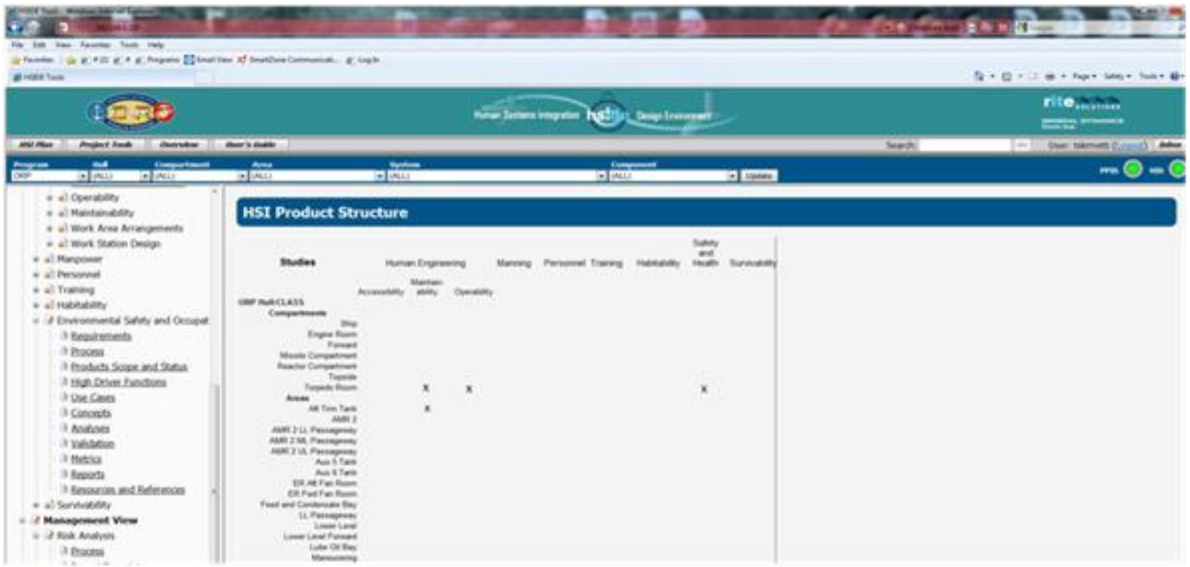


Figure 24: Program Scope Definition Matrix

When it is time to initiate the Torpedo Room maintainability analysis, the manager selects the workflow object and updates the first node to initiate the workflow. The workflow is then automatically sent to the owner of the first activity and the responsible individual receives a notification in their Inbox of a new work item. The new workflow is then automatically tracked through completion by the PLM.

In the future, it is envisioned that estimates for the different types of analysis will also be made available. Although it is difficult to estimate the exact amount of work necessary to support analyses of equipment of differing complexities, a system that ranks analyses into large, medium and small with corresponding man hour estimates for each size analysis, can be used to provide an early estimate of program costs.

The integrated risk assessment and product structuring, coupled with the man hour estimates, make it simple and easy for a program manager (customer) to rapidly assess and generate a desired scope for a program and then to negotiate an actual, affordable program scope (and budget) with the developer.

Finally, when linked with the management dashboard (discussed in the earlier Phase I report), the risk management, product scope and status and dashboard functionality allows managers to easily and efficiently track and manage program status and budgets throughout the entire life cycle of a design.

2.4 Refined methodologies to support manning estimation and validation

2.4.1 Process Refinement. Rite team members continued to expand and refine the manning estimation and validation process, including the development of a set of watchstander functional databases for VIRGINIA, OHIO and a set of proposed watchstander functions for OHIO Replacement (OR). The base process and supporting resources were successfully used to support a set of Command and Control System Module (CCSM) studies under a separate contract. Lessons learned from this application were factored back into the HSIDE Manning Estimation and Validation process. An excerpt from the updated Manning Estimation and Validation process is included as Figure 25.

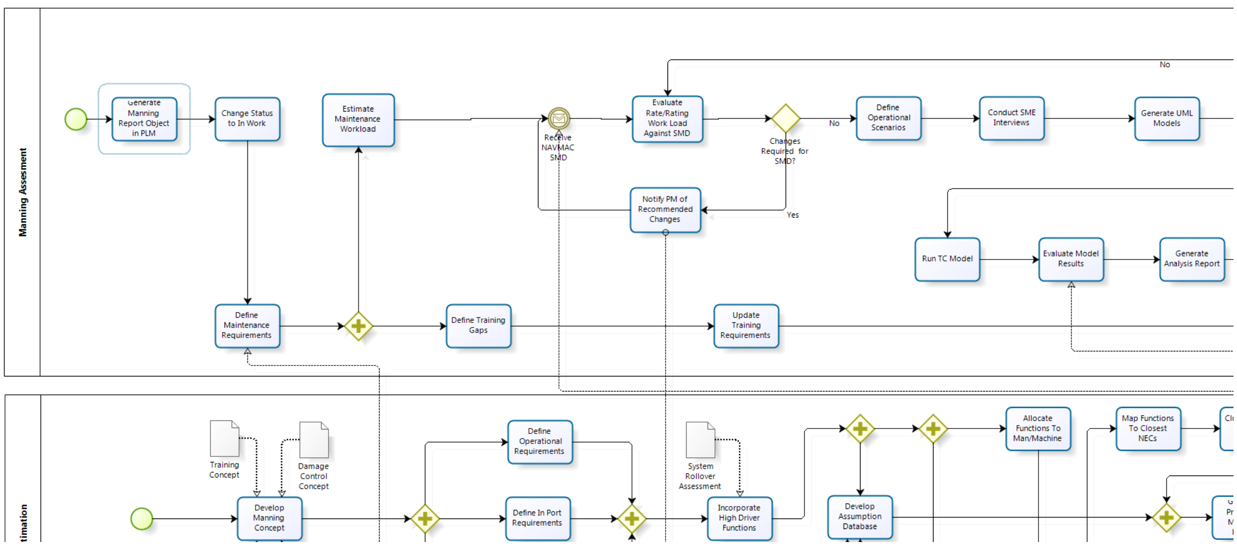


Figure 25: Excerpts from Updated Manning Estimation and Validation Process

2.4.2 Spreadsheet Development. A set of 3 spreadsheets were developed to assist analysts in determining watchbill requirements for various classes of submarines and to calculate the costs of various crew configurations.

The first spreadsheet is a comparison across the different classes (SSN and SSBN). The spreadsheet summarizes watchbill requirements for the LOS ANGELES, SEAWOLF, VIRGINIA, OHIO and projects OHIO Replacement watchbill organization. The spreadsheet addresses 3 main watch organizations: underway, maneuvering and battlestations. The spreadsheet is broken down by rate, area and watchstanding function. Using this spreadsheet, analysts can quickly compare watchstanding requirements across all major submarine classes. Figure 26 shows a portion of the class watchbill comparison.

UNDERWAY WATCH

	Watchstations	688	Seawolf	VA	OHIO	ORP
SHIP CONTROL	OOD	1	1	1	1	1
	JOOD	1	1	1	1	1
	JOOW					
	COW	1	1		1	
	DOOW	1	1		1	
	PILOT			1		1
	CO-PILOT			1		1
	HELMSMAN	1	1		1	
	PLANESMAN	1	1		1	
	MESSENGER	1	1		1	
	AOW	1	1	1	1	1
	AEF	1	1			
	Ship Cont Total	9	9	5	8	5
WEAPONS DEPARTMENT	FC SUPV		1		1	
	BMC Supervisor					1
	FTOW	1	1	1	1	
	LNCHR SUPV				1	1
	SWS Tech				1	1
	MC Roving Ptrl				1	1
	Cont Mont Pnl W				1	
	CC OTH Oper # 3					1
	SONAR SUPV	1	1	1	1	1
	TAWS OPER		1			
	SAWS OPER		1			
	WAA OPER					
	AUX OPER		1			

MANEUVERING WATCH

	Watchstations	688	Seawolf	VA	OHIO	ORP
BRIDGE	OOD	1	1	1		
	JOOD	1	1	1		
	Ph Talker (JA)	1	1	1		
	Ph Talker (1JV)	1	1			
	Lookout	1	1	1		
	Mk 43 Gunner		1	1		
	Whistle Oper		1	1		
	Bridge Total	5	7	6	0	0
TOPSIDE	Safety Officer	1	1	1		
	CPO (OIC)	1	1	1		
	POOD/Colors	1	1	1		
	Swimmer (Fwd/Aft)	1	2	2		
	CPO (Fwd)	1	1	1		
	CPO (Aft)	1	1	1		
	Capstan Oper	1	1	1		
	Line 1 Supv	1		1		
	Line 1 Handler	1	2	2		
	Line 2 Supv	1	1	1		
	Line 2 Handler	2	3	3		
	Line 3 Supv	1		1		
	Line 3 Handler	2	2	3		
	Line 4 Supv	1	1	1		
	Line 4 Handler	1	3	3		
	M-16			1		
	JA Fwd	1	1			
	JA Aft	1				

BATTLESTATIONS

	Watchstations	688	Seawolf	VA	OHIO	ORP
Ship Control	OOD	1	1	1	1	1
	JOOD				1	1
	DOOW	1	1		1	
	COW	1	1		1	
	AOW	1	1	1	1	1
	AEF	1	1		1	1
	Helmsman	1	1		1	
	Planesman	1	1		1	
	Lee Helm/Messenger	1	1	1	1	1
	Phone Talker JA	1	1	1	1	1
	Phone Talker 2JV	1				
	Pilot			1		1
	Co-Pilot			1		1
	Ship Cont Total	10	9	6	10	8
	Nav Technician			1		
	Navigator				1	
	Assistant Navigator				1	1
	DC Central			1		
	Photonics			1		
	Image Ops/Plots				1	1
	PLOTS					1
	OBTT			1		
	LTOW			1	1	1
	Network Security Tech				1	
	Peace Time Safety **					
	Approach Officer	1	1	1	1	1

SUMMARY

Underway Watch	688	Seawolf	774	OHIO	ORP
Ship Cont Total	9	9	5	8	5
Weaps Total	7	10	7	12	10
NAV/Comms Total	5	5	4	4	4
Eng'r Total	13	13	11	10	10
UnderWay Watch Total	34	37	27	34	29
Maneuvering Watch	**688**	**Seawolf**	**774**	**OHIO**	**ORP**
Bridge Total	5	7	6	Data Not Available	Data Not Available
Topside Total	20	21	24		
Ship Control Total	8	7	6		
Nav Team Total	18	14	12		
Sonar Total	5	4	5		
Radio Total	3	2	2		
Torpedo Rm Total	2	1	0		
DC Total	20	13	30		
Engineering Total	23	24	14		
AMR Total	2	2	2		
Shore Pwr Team Total	3	0	2		
LOT Total	0	0	3		
Misc Total	0	0	2		
Maneuvering W Total	109	95	108	0	0
Battlestations	**688**	**Seawolf**	**774**	**OHIO**	**ORP**

Figure 26: Excerpt from Class Comparison Spreadsheet

The second spreadsheet is a compendium of shipboard functions and the specified rates typically assigned to carry out those functions. This spreadsheet is used by analysts to assess the need for, and impacts of, technology insertion in current or proposed watchbills. Figure 27 shows an excerpt from the Shipboard Functions Spreadsheet.

Shipboard Functions

Row	A	B	C	D	Req'd for Mission Specific	Req'd for Cond I Torpedo	Req'd for Cond I STRIKE	Req'd for Cond I MISSILE	Req'd for Cond III	CO	XO	NAV	OOD	TAO	Pilot	PFM	Sensor	EOOW	Pwr/Prop	System	Offboard	VIRGINIA Watch / Individual that will accomplish this function
124	Maneuver to Achieve Aim	Monitor	Maneuvering Sytems Status	Mode & Configurations									X		X					X		
125	Maneuver to Achieve Aim	Monitor	Maneuvering Sytems Status	Operating Indicators Mast Antennas & Hull Openings											X					X		
126	Maneuver to Achieve Aim	Monitor	Record	Log Data & Orders																X		
127	Maneuver to Achieve Aim	Assess	Speed/Depth	Safety of Operations / Compute Projected Speed/Depth																X		
128	Maneuver to Achieve Aim	Assess	Safety of Operations	Compare Projected Speed/Depth vs SOE																X		
129	Maneuver to Achieve Aim	Assess	Maneuvering Progress	Compare Actual vs Ordered Speed/Depth/Handling																X		
130	Maneuver to Achieve Aim	Assess	Maneuvering Progress	Compare current vs New Ordered Speed/Depth/Handling																X		
131	Maneuver to Achieve Aim	Assess	Bouyancy / Trim State	Projected Trends in Parameters																X		
132	Maneuver to Achieve Aim	Assess	Bouyancy / Trim State	Bouyancy / Movement / Condition / Trends																X		
133	Maneuver to Achieve Aim	Assess	Bouyancy / Trim State	Recognize Flooding Conditions											X					X		
134	Maneuver to Achieve Aim	Assess	Ship's Movement	Relative to fixed objects, Nav Aids, Hazards & moving contacts									X		X					X		
135	Maneuver to Achieve Aim	Evaluate / Decide	Motion Control Options	Eval Plane Angles																X		
136	Maneuver to Achieve Aim	Evaluate / Decide	Motion Control Options	Eval Ship Angle																X		
137	Maneuver to Achieve Aim	Evaluate / Decide	Ballast & Trim Options	Compute Compensation																X		
138	Maneuver to Achieve Aim	Evaluate / Decide	Ballast & Trim Options	Eval Water Movement																X		
139	Maneuver to Achieve Aim	Evaluate / Decide	Ballast & Trim Options	Eval Tank Blowing/Pumping/Flooding																X		
140	Maneuver to Achieve Aim	Evaluate / Decide	Ballast & Trim Options	Eval Ship Angle																X		
141	Maneuver to Achieve Aim	Evaluate / Decide	Ballast & Trim Options	Eval Ship Speed																X		

Figure 27: Excerpt from Shipboard Functions Spreadsheet

The third spreadsheet is a cost calculator for direct and indirect costs of various crew configurations, data is based on the Navy's Cost of Manpower Estimating Tool (COMET) tool and calculates inflated costs for a given fiscal year. Data can be calculated for overall crew size or for a specific watchbill. This allows analysts to determine the limiting manning configuration for cost. Figure 28 shows an excerpt from the Cost Comparison Worksheet.

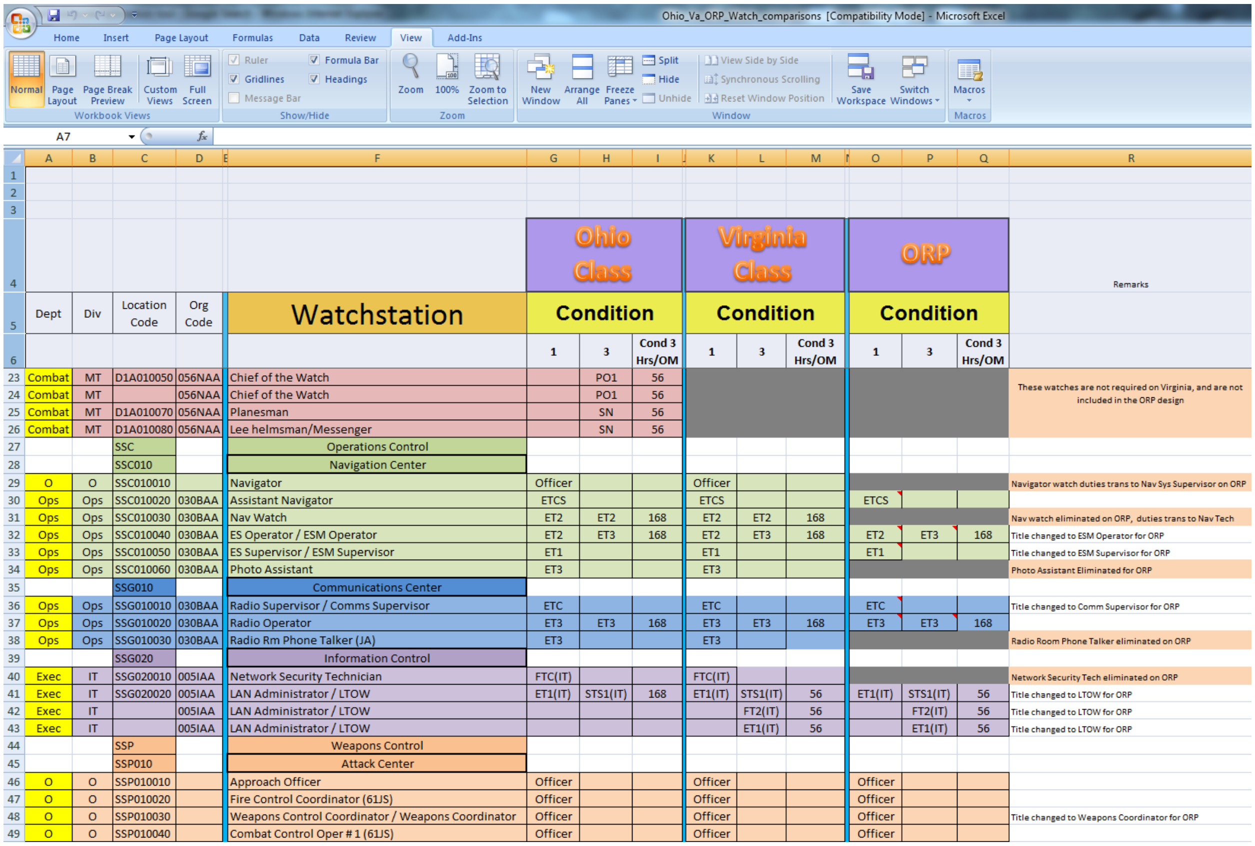
Cost Comparison (Year 2019) Virginia Blk III vs CSoF CACC

Cond III CACC Watches		
Rank /Rate	**Va Blk III**	**CSoF CACC**
ETC		1
ET2	1	1
ET3	2	
FT2		1
FT3	1	
MMC	1	1
MM2		1
MM3	1	
POCS	1	
POC		1
STS1	2	1
STS2		1
STS3	3	
STSSN	1	

Cond III CACC Watches		
Rank /Rate	**Va Blk III**	**CSoF CACC**
ETC		$185,815.20
ET2	$151,708.30	$151,708.30
ET3	$273,164.00	
FT2		$150,932.30
FT3	$134,004.90	
MMC	$159,092.70	$159,092.70
MM2		$125,971.50
MM3	$110,608.40	
POCS	$186,349.50	
POC		$169,280.70
STS1	$318,427.20	$159,213.60
STS2		$142,689.50
STS3	$383,976.30	
STSSN	$115,179.00	
Total	$1,832,510.30	$1,244,703.80

Figure 28: Excerpt from Cost Comparison Spreadsheet

The set of spreadsheets make it easy for an analyst to assess the baseline watchstanding requirements for a new class and to modulate that model based on factors such as new CONOPs, technology insertion, changes in operational doctrine, etc. Figure 29 illustrates the use of the spreadsheets when developing a manning plan for the OHIO Replacement using OHIO Class as the baseline and VIRGINIA Class requirements derived from expected system rollovers.



	Dept	Div	Location Code	Org Code	Watchstation	Ohio Class Condition 1	Ohio Class Condition 3	Ohio Class Cond 3 Hrs/OM	Virginia Class Condition 1	Virginia Class Condition 3	Virginia Class Cond 3 Hrs/OM	ORP Condition 1	ORP Condition 3	ORP Cond 3 Hrs/OM	Remarks
23	Combat	MT	D1A010050	056NAA	Chief of the Watch		PO1	56							These watches are not required on Virginia, and are not included in the ORP design
24	Combat	MT		056NAA	Chief of the Watch		PO1	56							
25	Combat	MT	D1A010070	056NAA	Planesman		SN	56							
26	Combat	MT	D1A010080	056NAA	Lee helmsman/Messenger		SN	56							
27			SSC		Operations Control										
28			SSC010		Navigation Center										
29	O	O	SSC010010		Navigator	Officer			Officer						Navigator watch duties trans to Nav Sys Supervisor on ORP
30	Ops	Ops	SSC010020	030BAA	Assistant Navigator	ETCS			ETCS			ETCS			
31	Ops	Ops	SSC010030	030BAA	Nav Watch	ET2	ET2	168	ET2	ET2	168				Nav watch eliminated on ORP, duties trans to Nav Tech
32	Ops	Ops	SSC010040	030BAA	ES Operator / ESM Operator	ET2	ET3	168	ET2	ET3	168	ET2	ET3	168	Title changed to ESM Operator for ORP
33	Ops	Ops	SSC010050	030BAA	ES Supervisor / ESM Supervisor	ET1			ET1			ET1			Title changed to ESM Supervisor for ORP
34	Ops	Ops	SSC010060	030BAA	Photo Assistant	ET3			ET3						Photo Assistant Eliminated for ORP
35			SSG010		Communications Center										
36	Ops	Ops	SSG010010	030BAA	Radio Supervisor / Comms Supervisor	ETC			ETC			ETC			Title changed to Comm Supervisor for ORP
37	Ops	Ops	SSG010020	030BAA	Radio Operator	ET3	ET3	168	ET3	ET3	168	ET3	ET3	168	
38	Ops	Ops	SSG010030	030BAA	Radio Rm Phone Talker (JA)	ET3			ET3						Radio Room Phone Talker eliminated on ORP
39			SSG020		Information Control										
40	Exec	IT	SSG020010	005IAA	Network Security Technician	FTC(IT)			FTC(IT)						Network Security Tech eliminated on ORP
41	Exec	IT	SSG020020	005IAA	LAN Administrator / LTOW	ET1(IT)	STS1(IT)	168	ET1(IT)	STS1(IT)	56	ET1(IT)	STS1(IT)	56	Title changed to LTOW for ORP
42	Exec	IT		005IAA	LAN Administrator / LTOW					FT2(IT)	56		FT2(IT)	56	Title changed to LTOW for ORP
43	Exec	IT		005IAA	LAN Administrator / LTOW					ET1(IT)	56		ET1(IT)	56	Title changed to LTOW for ORP
44			SSP		Weapons Control										
45			SSP010		Attack Center										
46	O	O	SSP010010		Approach Officer	Officer			Officer			Officer			
47	O	O	SSP010020		Fire Control Coordinator (61JS)	Officer			Officer			Officer			
48	O	O	SSP010030		Weapons Control Coordinator / Weapons Coordinator	Officer			Officer			Officer			Title changed to Weapons Coordinator for ORP
49	O	O	SSP010040		Combat Control Oper # 1 (61JS)	Officer			Officer			Officer			

Figure 29: Excerpt from Watchbill Comparison Spreadsheet

2.5 Metrics

Previously, most metrics defined for Human Systems Integration (HSI) have focused either on the quality of the resulting products or the effectiveness of those products in enhancing human performance. As an example, HSI Port presents a set of HSI metrics that includes measures such as berths per compartment, number of billets required for each NEC/ required skill object set, or number of hours of rest per 24 hour period. As another example, MIT's Humans and Automation Laboratory (HAL) presents a selection of metrics classes based on user/system performance including mission effectiveness, human behavior efficiency and collaborative metrics (Pina, Donmez and Cummings, 2008).

The initial metrics report provided under this project ("Framework and List of Metrics (Measures) for HSIDE Evaluation") discussed this full range of HSI-associated measures. In this follow on report, however, the focus of the metrics definition is to support product transition and is focused specifically on the utility of applying HSIDE in a production design environment. The intent is to specify a set of measures that would guide data collection in the next design program to provide useful information that will allow assessment of how well HSIDE supports and integrates with the production design process as the design progresses.

As HSIDE development and prototyping has progressed through Phase I, the initial set of proposed measures associated with design yard utility was reviewed. Our team member, Electric Boat plans to collect data that will help assess performance and effectiveness regarding the accomplishment of HSI work associated with the next design. To this end, selected data will be collected as the next submarine design program progresses through concept and detailed design to help observe and assess any trends relative to the accomplishment of HSI activities.

As Electric Boat became more and more familiar with HSIDE and the HSI requirements, the original list of measures was superseded with a list tailored to reflect how Electric Boat could potentially monitor HSI utility in a production environment. As part of the HSIDE effort, Electric Boat generated a list of data items that could be collected during the next design program.

The data identified by the design yard focuses on how effectively HSI integrates with and supports the design enterprise, adding value to the end product while contributing to the minimization of acquisition cost, total ownership cost, downstream design rework, schedule delay, etc. In other words, they support determination of what degree HSI contributes to faster, better, more affordable and more effective designs. The problem is there are currently no target or objective goals established against which to apply this data. The planned HSIDE target, the OHIO Replacement Program is in the very early stages of program startup and there is no formal HSI program budget or schedule to support the establishment of target objectives for most of the above listed measures.

Another problem is the lack of baseline data available to support HSI program assessment. In the submarine context, there is no baseline HSI data from previous design programs against which to develop objective or threshold criteria or to compare the performance and benefits accrued from one program to another. Therefore, the original Electric Boat list contains measures and, in some cases, attributes that may be used to collect data on the next design effort but does not include threshold or objective measures.

It has been stated by numerous sources, including GAO, MOD and SEA05H that performing HSI early in the design process will lead to increases in human performance, safety, maintainability and habitability and decreases in workload and MP&T requirements. Although the EB proposed metrics can ultimately provide a wealth of data that can be used to accurately assess an HSI program, there is currently no baseline to support comparisons and therefore, no real indication of how well the HSI program is doing. Thus, the metrics proposed by the Rite-Solutions' team focus on a very small set of metrics that can be used to both easily measure the accomplishment of HSI activities relative to progress in the design process, and that should correlate with the benefits expected to accrue to a program based on timely performance of HSI analyses. That is, it is assumed that the actual performance of the HSI activities will contribute to the accomplishment of the stated HSI objectives.

Since the design process is dominated by the drawing (expected in the future to shift to 3D model) issue or arrangement model approval schedule, HSI progress is assessed

relative to their completion percentage of drawings issued, arrangement models approved by the Major Area Teams (MAT), or to major steps in the DOD 5000.2 process. It should be noted that ship design differs from the standard 5000.2 process in that lead ship construction (low rate initial production) is authorized prior to Milestone C and that difference is reflected in the metrics. It should also be noted that these measures are directed only at the design yard and are not applicable to the programmatic processes that occur before design yard involvement (i.e., Analysis of Alternatives (AoA)).

To support program assessment on a new HSI design program, at least at a course-grain level, Rite-Solutions proposed a small, focused set of metrics to supplement the collection of the proposed Electric Boat measures and provide an opportunity to do in-stride assessment of the ongoing program.

These metrics are correlated to the expected benefits of applying HSI in a design program and reflect the schedule requirements that must be satisfied for the HSI processes to have the greatest influence. These metrics include not only pertinent measures but also take into account the ability to actually obtain the data necessary to assess these measures in a real world production environment. This small set of metrics can also be used to assess HSI performance within a single program without the need for data from a previous program.

Rite-Solutions' recommended HSI measures of effectiveness (MOEs) are summarized in Table 1. Associated measures of performance (MOPs) are discussed in the following text.

	Recommended Metric
1	Identify/disposition all major HSI impacts early in program
2	Reduce maintenance workload
3	Improve personnel safety
4	Improve shipboard habitability
5	Enhance human performance
6	Reduce program life cycle costs

Table 1: Recommended MOEs

An example of the in-stride metrics is presented below:

MOE: Identify/disposition all major HSI impacts early in design process

MOP: Percentage of major HSI impacts identified/dispositioned prior to specified percentage of drawings issued.

Threshold: All major HSI impacts identified/dispositioned prior to 75% of planned drawings issued

Measure: The number of major HSI impacts identified/dispositioned before 75% of planned drawings issued divided by total number of HSI impacts identified/dispositioned prior to ship delivery (percentage).

Objective: All major HSI impacts identified/dispositioned prior to 90% of drawings issued.

Measure: The number of major HSI impacts identified/dispositioned before 90% of planned drawings issued divided by total number of HSI impacts identified/dispositioned prior to ship delivery (percentage).

Rationale: Drawing issue is a major factor in ship design. If major HSI impacts can be identified/dispositioned before drawing issue is complete, it minimizes the number of drawing changes that can be expected in the remainder of the program. In addition, problems identified/dispositioned after the start of construction are much more expensive to correct than problems that can be addressed during the design process. Therefore, identifying/dispositioning major HSI impacts early in the program minimizes downstream work impacts, minimizes construction rework, and reduces costs associated with human-centered design changes. Since responsibility for ship design passes from design yard to planning yard at delivery, the above analysis is based on major impacts identified/dispositioned only up to delivery and does not reflect impacts identified /dispositioned during the ship's operational life.

Note: As stated earlier, in the future, drawings are expected to be replaced by 3D models. In this case, the wording associated with drawings should be changed to reflect the use of models. As an example, "…prior to X% of models approved." A complete definition and discussion of the recommended in-stride metrics is presented in Rite-Solutions (2010).

Encapsulating program accomplishments in a manageable number of meaningful, easy to measure metrics that can be assessed during program execution provides several advantages. First, they provide a first order assessment of how well the HSI program is being executed. They also give an indication of how much input HSI is providing to the design process. Finally, they provide a correlated measure of the impact, from a human perspective, that the HSI process is having on improving the quality of the overall design.

Although Table 3 currently represents an almost 1:1 mapping of MOEs to MOPs, it is expected that, as additional information is collected on the next program, additional MOPs will be generated in the future for each MOE. The proposed Electric Boat data collection can provide a wealth of data which can be used to assess trends within a program and to establish a baseline with which to assess future programs. It is expected that data collection on a new program will apply the Electric Boat recommended measures to assist in in-stride assessment of the program while building a database with which to support future program comparisons, while the Rite-Solutions' recommended measures will support in-stride assessment of the ongoing program. As OR HSI requirements mature, many of the Electric Boat proposed measures can be refined and used to expand the available measures of performance and provide a more comprehensive assessment of HSI performance in a new design program.

2.6 Developed Methodology to Optimize Team Arrangements

Knowledge engineering sessions with SMEs and customer comments obtained during Combat System of Future demonstrations (Rite-Solutions, 2009) have shown that reconfigurability of the Control Room spaces is a desired capability. The ability to re-arrange the layout of the watchstanders to reflect specific mission requirements was expected to provide an improvement in overall team performance and mission effectiveness. In addition, even if reconfigurability is not a requirement, optimizing the relationships between watchstanders to suit the widest range of missions is desirable.

To this end, a methodology was developed to generate optimal, mission-based arrangements derived from proposed CONOPs and the resulting communications/watchstander interaction requirements.

2.6.1 CONOPs

The subject content used was a hypothetical CONOPs for a command and control center developed under Rite-Solution's Combat System of the Future. Under this CONOPs, the following watchstations and duties were posited:

(1) **Officer of the Deck (OOD).** Same as VIRGINIA Class;

(2) **Navigator.** Same as VIRGINIA Class. Note that integration of Pilot/Nav duties generates a shift in interaction between the Navigator and the Pilot/Nav rather than the Quartermaster;

(3) **Pilot-Nav.** This position integrates ship control and routine navigation functions under a single operator. The Pilot is responsible for the maintenance of, course, speed and depth, and ship's list and trim. In the future organization, the pilot also assumes the duties of the QM of the Watch (e.g., maintaining the plot, contour fixes, and soundings). This does not replace the function of Navigator. It is expected that the current Voyage Management System (VMS) will continue to evolve and much of the routine navigation functions will be automated, resulting in a minimal level of required supervision during

open ocean transit. For high intensity navigation evolutions (e.g., maneuvering watch, strike, and ISR), it is expected that a full time navigator will be stationed to address navigation functions;

(4) **Platform Manager.** Manages all ship's HM&E systems and functions, including operation and oversight of all ship's equipment, controlling ship's signatures and managing ship's rigs;

(5) **Contact Manager**. Responsible for overall contact management, including identification, classification, localization and tracking for integrated sensor systems contacts. The contact manager is assisted by a Sensor Manger;

(6) **Payloads Manager.** Manages the preparation, mission planning, launch, management and retrieval of all payloads (e.g., weapons, countermeasures, and unmanned vehicles);

(7) **Information Manager.** Manages all internal and external communications requirements and maintains all shipboard networks and information systems. Buoy management is a major concern for the strategic submarine mission. As such, it is anticipated that the buoy communication functions may be incorporated in the information manager workstation. This will allow close collaboration between the buoy (information) manager and the pilot;

(8) **Sensor Manger**. This member would analyze and exploit all ship's sensors including acoustic, ESM, radar, etc.

2.6.2 Communications Matrices

A set of communication matrices were then developed to estimate the communications requirements between the various watchstations for each major mission type. Figure 27 shows a sample communications requirement matrix for the mobility mission.

MOBILITY MISSION

	OOD	Navigator	Pilot	Platform Manager	Contact Manager	Payloads Manager	Information Manager	Sensor Manager
OOD								
Navigator	H							
Pilot	H	H						
Platform Manager	H	L	H					
Contact Manager	H	L	L	L				
Payloads Manager	H	L	L	L	H			
Information Manager	H	M	M	M	M	L		
Sensor Manager	H	L	H	H	H	L	M	

Figure 30: Example Communications Requirements Matrix

2.6.3 Optimization Routine

After the communications matrices had been developed with the SMEs, a linear optimization program was used to determine the optimal arrangement to support team communication requirements. The methodology was as follows:

The objective of this exploration is to find an optimal seating arrangement for submarine watchstanders in a command and control room. The arrangement is to be optimized by minimizing the distance between pairs of watchstanders who frequently communicate. Formally, consider the problem of allocating a group of watchstanders to a set of possible watchstation locations. Each pair of watchstanders has a certain communication level – high, medium, or low, and each pair of possible watchstation locations has a certain associated distance. The 'cost' here is a function of the distance and communication flow amongst watchstander-location pairings. The objective is to assign each watchstander to a location for their watchstation such that the 'cost' is minimized. Specifically, we are given two input matrices with real elements C = (   ) and D = (   ), where   is the communication level between watchstander   and watchstander , and   is the distance from location i to location j. The matrices C and D are nonnegative symmetric sized   and   respectively.

The problem can be formulated as follows:

Let m be the number of watchstanders and n be the number of possible watchstander locations.

Each individual product is the 'cost' of assigning watchstander i to watchstation location j. Each permutation of the sets and , can be represented by an matrix such that

Matrix is called a permutation matrix and is characterized by the following constraints:

(1)
(2)
(3)
(4)

Constraint 1 states that each watchstander must be assigned to exactly one seat. The second constraint complements the first by imploring no more than one watchstander may be assigned to each seat. The inequality is present here because we define , so there are more possible watchstation locations than watchstanders. The third constraint dictates that all watchstanders must be assigned to unique watchstation locations. The final constraint insures that the entry values in matrix are strictly binary.

In the scenario we explored, 19 possible watchstation locations are arranged and numbered as follows:

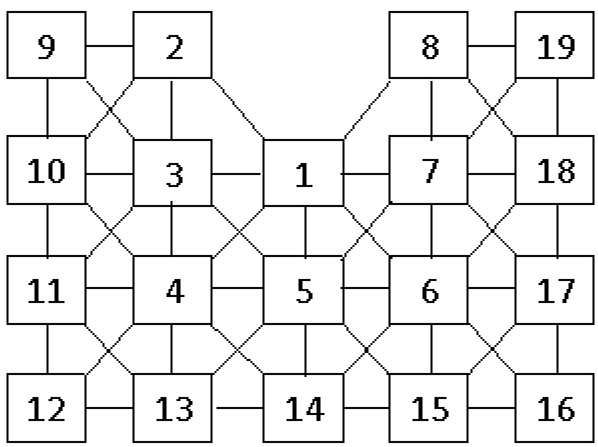


Figure 31: Potential Watchstander Locations

The distance between watchstation locations and is definied by the number of line segments traversed in the shortest path from watchstation location to watchstation location . For example, the distance between watchstation locations 11 and 19 is defined as four because you cannot reach location 19 from location 11 without traversing at least four line segments. There are eight watchstanders to be arranged to unique watchstation locations including the Officer of the Deck (OOD), Navigator (Nav), Pilot, Platform Manager (PM), Contact Manager (CM), Payloads Manager (PayM),

Information Manager (IM), and Sensor Manager (SM). The watchstanders are assigned identification numbers one through nine, respectively.

Matrices were provided by subject matter experts (SMEs) indicating level of communication between pairs of watchstanders for each of the seven missions explored. In order to implement the model, each communication level is assigned a numerical equivalent to allow for mathematical optimization. Namely, a pair with a low level of communication is assigned a numerical value of 10, medium a value of 50, and high a value of 90. An additional constraint was added by the SMEs specifying that the OOD occupies watchstation location one. The quadratic integer program can be formulated as follows:

This formulation is implemented in Excel and solved using Excel's add-in, Premium Solver Platform 5.0. This add-in can handle mixed-integer constrained linear and nonlinear programs of up to 2000 variables. The results are optimal, though not necessarily unique.

2.6.4 **Results**

In order to test the validity of the model, a test scenario was created with a communication matrix labeled "Test" in Appendix A and all other model inputs consistent with the mission scenarios. The communication matrix was constructed based on a predefined seating arrangement which looks like this:

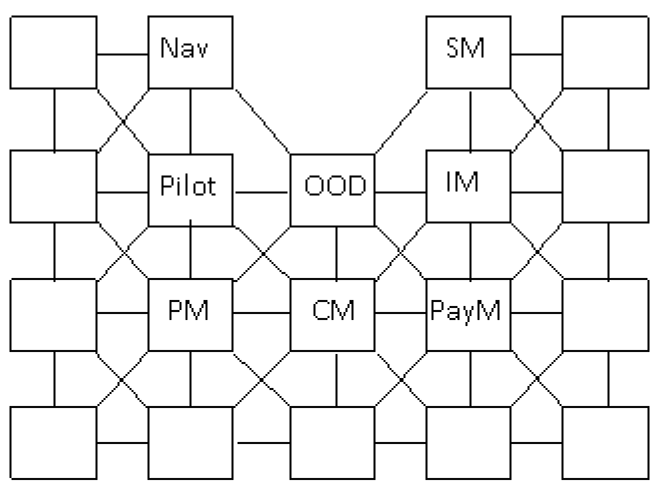


Figure 32: Test Seating Arrangement

This is just one optimal solution for the communication matrix associated with it. The optimal solution that is generated by the Premium Solver Platform model is a mirror image of the above arrangement, which maintains the distance measurements between all pairs of watchstanders. Therefore, an optimal solution is found and the model is validated.

The optimal results generated for the missions explored are shown as seating arrangements below.

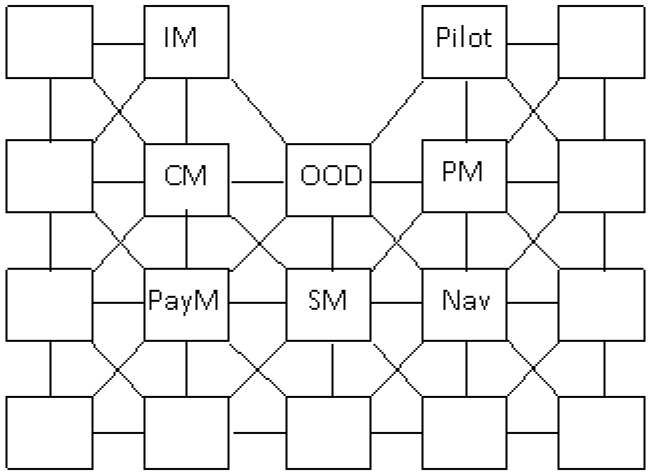


Figure 33: Optimal Seating Arrangement

An example of the optimization methodology is provided for the mobility mission. Eleven of the thirteen watchstander pairs (approximately 85%) in the mobility mission with a high level of communication are just one distance unit away from each other. The other two pairs with a high communication level are two distance units away, namely the Pilot-Navigator and Pilot/Sensor/Manager pairs. All pairs with a medium level of communication are within two distance units of one another. The same can be said for pairs with low levels of communication since in this particular arrangement the maximum distance between any pair is two distance units.

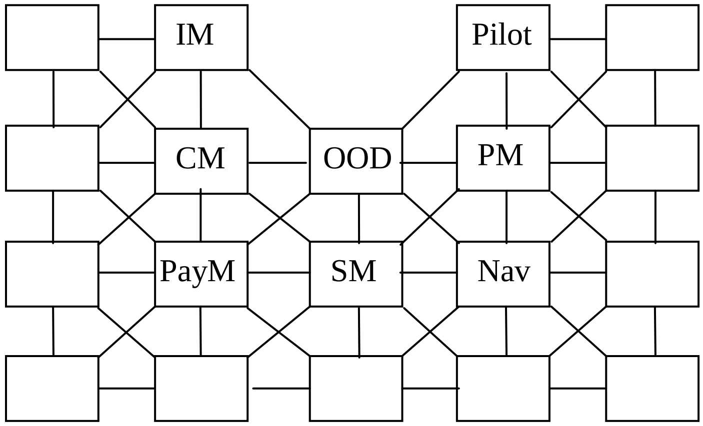


Figure 34: Optimal Seating Arrangement for Mobility Mission

Analyses were performed for the following mission areas:

1) Mobility
2) ASW
3) Strike
4) ISR
5) SOF
6) ASUW
7) MW

Following the analysis of the individual mission arrangements, 2 further analyses were performed. In the first, the mobility mission and the ISR Missions were mapped and weighted to reflect their frequency normal peace time operations. According to SME input, ISR was the major peace time mission. The mobility mission is required or any submarine operation and was weighted at 75%. The ISR mission was weighted at 25%. The arrangemnts were then optimized to reflect these weightings. The results are shown in Figure 32.

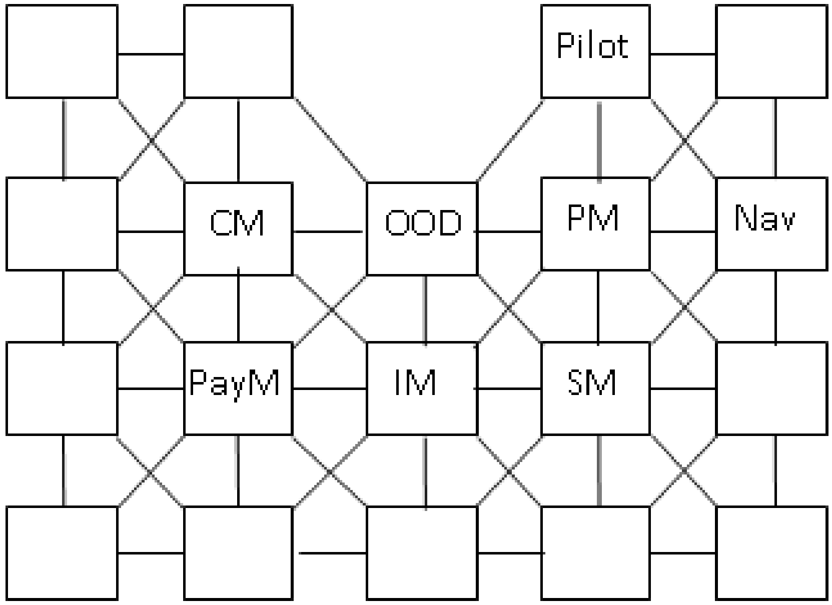


Figure 35: Weighted ISR and Mobility Mission Arrangement

The second analysis provides an unweighted composite of the arrangements across all the various missions. The results for this analysis are illustrated in Figure 33.

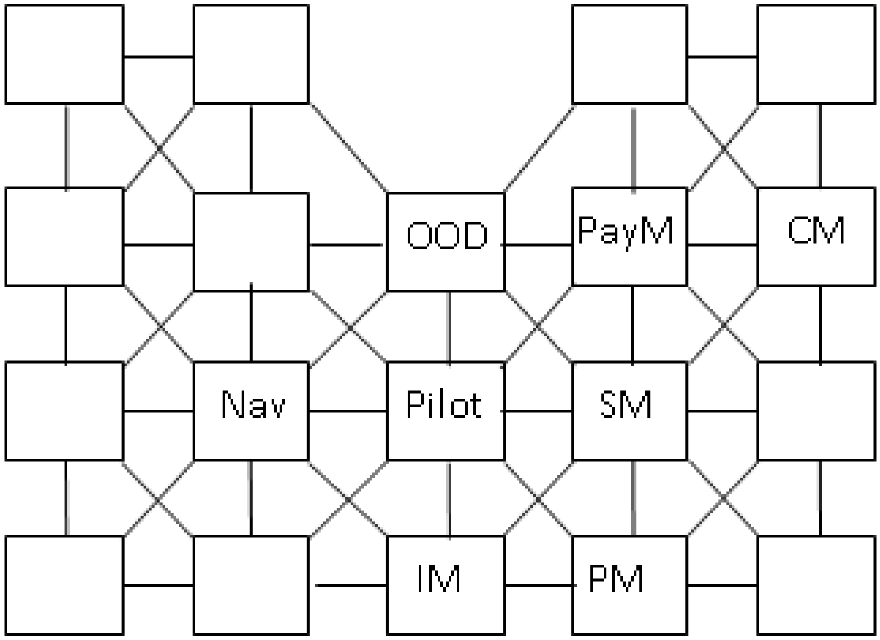


Figure 36: Unweighted Mission Composite Arrangement

2.6.5 VIRGINIA Class Example

In order to test the model, the team reviewed the current VIRGINIA class command and control room arrangement and applied the model to the watchstander functions active during a complex mobility mission with the following watchstanders:

OOD
JOOD
Pilot
Copilot
Messenger (Free Floating Watch)
Navigator (Free Floating Watch)
Assistant Navigator
Navigation Watch
Combat (Fire) Control Operator (2)
Sonar Supervisor (Free Floating Watch)
Sonar Operators (3)
Sonar Auxiliary Operator

Note that there are normally not specific watchstation locations assigned for the Messenger, Sonar Supervisor and Navigator as they tend to move from location to location to carry out their duties. A typical VIRGINIA watchstation layout is shown in Figure 37.

<table>
<tr><td></td><td></td><td>Pilot</td><td>Copilot</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Mess</td><td></td><td colspan="2" rowspan="2">OOD</td><td></td><td>CCO #1</td></tr>
<tr><td>SO #3</td><td></td><td></td><td>CCO #2</td></tr>
<tr><td>SO #1</td><td></td><td></td><td>JOOD</td><td></td><td></td></tr>
<tr><td>SO #2</td><td>Son Sup</td><td></td><td></td><td></td><td></td></tr>
<tr><td>Son AuxOp</td><td></td><td></td><td></td><td></td><td>Nav Watch</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Asst Nav</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Nav</td></tr>
</table>

Figure 37: Typical VIRGINIA Class Watchstander Arrangement

The team wanted to assess how the current arrangement would compare to the arrangement chosen by the model. In this case there were twenty watchstation locations to choose from and fifteen watchstanders to place. Equipment location was not considered fixed. The possible watchstations were arranged as follows:

<table>
<tr><td></td><td></td><td>1</td><td>2</td><td></td><td>3</td></tr>
<tr><td>17</td><td></td><td></td><td></td><td></td><td>4</td></tr>
<tr><td></td><td></td><td rowspan="2" colspan="2">18</td><td></td><td>5</td></tr>
<tr><td>16</td><td></td><td></td><td>6</td></tr>
<tr><td>15</td><td></td><td>19</td><td>20</td><td></td><td>7</td></tr>
<tr><td>14</td><td></td><td></td><td></td><td></td><td>8</td></tr>
<tr><td>13</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>12</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>11</td><td></td><td>10</td><td>9</td><td></td><td></td></tr>
</table>

Figure 38: Model of Possible VIRGINIA Class Arrangement Space

In the case of a quadratic assignment problem, any increase in problem dimension increases the complexity of finding an optimal solution exponentially. The software used previously is not powerful enough to find a solution to this new problem in a timely manner, so we employed a genetic algorithm instead. We chose to use Palisade's Evolver 5.7, a genetic algorithm for Excel optimization. Using the same model created previously and a new communication matrix provided by the subject matter experts (see Appendix A), Evolver came up with the following solution:

<table>
<tr><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td>Nav Watch</td></tr>
<tr><td></td><td></td><td colspan="2" rowspan="2">OOD</td><td></td><td>Asst Nav</td></tr>
<tr><td>Mess</td><td></td><td></td><td>Nav</td></tr>
<tr><td>Copilot</td><td></td><td>Pilot</td><td>JOOD</td><td></td><td>CCO #1</td></tr>
<tr><td>SO #3</td><td></td><td></td><td></td><td></td><td>CCO #2</td></tr>
<tr><td>SO #1</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Son Sup</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SO #2</td><td></td><td>Son Aux Op</td><td></td><td></td><td></td></tr>
</table>

Figure 39: System-Generated Arrangement for VIRGINIA Control Room

2.6.5 Discussion

It is important to note that the solutions found in this study represent logical arrangements, rather than physical ones. The physical arrangements could be laid out as the mirror image of the solutions seen here, or rotated, etc. The solutions are simply analytical guides for the physical arrangement of a command and control room.

At first glance, the solutions generated by the algorithm for the VIRGINIA Class example do not seem to fit the actual arrangements. Upon closer examination, the results actually provide a surprisingly good fit. The layout shows the Pilot/Co-Pilot in a different configuration than the VIRGINIA Control Room layout. When examined more closely, the distance between the Pilot/Co-Pilot and OOD are actually the same as the VIRGINIA Model, only the Pilot/Co-Pilot are located forward in the VIRGINIA Control Room rather than next to the OOD. In the actual VIRGINIA layout, this relationship is constrained by the location and space requirements associated with the Ship Control Station. The model, lacking these constraints, recommended a different arrangement but maintained the logical separation. Similar results were found for the other watchstations. Although sometimes arranged in a mirror image of the actual VIRGINIA layout, general degrees of separation/distance were maintained for all watchstations.

The important thing to remember when considering this arrangement is that the quality of arrangement is directly correlated with the quality of input. So if, for example, it was more desirable that the Pilot and Copilot sit next to each other rather than having the Pilot sit next to the JOOD, then the communication matrix would have to be structured

to reflect that preference. In this case, the two pairs' communication levels are considered equal, both labeled 'high.' Also, no physical constraints were put into the model other than the locations of possible watchstation locations. Although the Copilot should be facing front, there is no constraint in the model that says so, so the model does not consider this necessity and the Copilot ends up facing port in this solution. There are many more constraints that should be considered in this model, but the point of this exercise is to see how the algorithm's results compare to the current VIRGINIA arrangement.

Upon researching, a similar problem was found known as the Quadratic Assignment Problem (QAP). This problem was introduced by Koopmans and Beckmann in *Assignment Problems and the Location of Economic Activities* (Koopmans and Beckmann, 1957). The main difference between the previously presented model and Koopmans and Beckmann's version is the latter defines a one-to-one correspondence between the locations and actors. In the submarine command and control room model, eight watchstanders are assigned to eight of nineteen possible locations whereas the QAP has the same number of actors as locations. The problem remains NP-hard.

This methodology and tool allows designers to quickly generate proposed arrangements using preliminary CONOPs and requirements early in a program. It should be noted that this methodology defines the optimal logical relationship between watchstanders and not the actual arrangement as executed in the physical dimension. Ulitmately, arrangements will be determined by the recommendations of tools such as this with compromises to suit the actual volume and shape of the space actually available to accommodate the team.

2.7 Completed Level A Technology Transition Agreement

A Level A Technology Transition Agreement (TTA) was signed on April 18, 2011 between the ONR Sponsor, N87 and the OHIO Replacement Program Office (PMS397). In accordance with the final TTA, the focus of the remaining development on the HSIDE prototype design environment will be on the development of maintenance, operability and Environmental Safety and Occupational Health (ESOH) products in support of increased efficiency in the OHIO Replacement program design effort.

2.8 Completed final prototype evaluation with Electric Boat

2.8.1 TTA Direction and Scope

The Level A TTA specified that the remaining HSIDE effort on the areas where the design yard and PMS397 thought they would obtain the most benefit in increasing design yard HSI efficiency and improving the quality in the OHIO Replacement design. The TTA stated that the 3 areas to be addressed were: maintainability, operability and ESOH. The planned processes were once again reviewed by design yard SMEs and numerous changes were made to the existing workflows. This caused a slip in planned schedule and the evaluation period was extended from the original schedule date of September 2011 to December 2011. The evaluation was completed in December.

2.8.2 Workflow Revisions

Preliminary workflows for all HSI areas were generated by the project team based on HSI best practices as defined in SEA05H HSE Best Practices Guide, the Virtual SysCom and the MOD Standards for Human Factors Design. These initial processes were then provided to the design yard in BPMN standard format for review and comment. Based on design yard feedback, these initial processes were revised and incorporated in the Phase I prototype workflows.

The processes were extensively revised between Phase I and Phase II. Following the signing of the Level A TTA, the existing workflows for maintainability, operability and ESOH were again re-assessed by the design yard and further extensive changes were recommended and incorporated into the Phase II prototype.

2.8.3 Evaluation Process

The Phase II evaluation involved a use case scenario of adding a fuel cell power system to a new submarine design. Electric Boat personnel assessed the fuel cell power generation system using the HSIDE prototype at the user's normal desktop locations using 3 sets of workflows: Environmental, Safety and Occupational Health; Maintainability; and Operability. The workflow evaluations were conducted over a six week period. Three of the seven Electric Boat subject matter experts performing the evaluation had previous experience using electronic workflow-based applications.

The execution of the workflows in the HSIDE environment provided the opportunity for Electric Boat to evaluate how working in a HSIDE-like environment could support future design efforts and also identified areas where such a system restricted the user based on a pre-programmed path.

Each participant provided comments as to how the process worked as they executed the different steps of the workflows. Rite-Solutions' software engineers corrected problems and addressed any identified anomalies in real time, resulting in only minor interruptions of the testing during prototype execution.

2.8.4 Evaluation Results

Users determined HSIDE workflow can accomplish the following:

a. Eliminate tracking of Safety Analysis "To Do" list;

b. Replace Planned maintenance tracking database;

c. Reduce use of individually generated e-mails;

d. Provide status updates to management;

e. Prompt management intervention on stalled tasks;

f. Promote accountability.

Electric Boat provided specific comments on workflow features they found useful in the prototype. These features included:

a. Reference library that included standards, system descriptions, system data, etc.;

b. Workflow diagrams that provided a visual interaction with the analysis process which helped to establish a higher level of cognitive engagement with the work;

c. Task tables which listed each individual task associated with each node in the workflow;

d. E-mail notification sent to the users to notify them of a pending activity;

e. The functionally-oriented HSIDE web interface.

Electric Boat users also identified several workflow features not found in HSIDE but which the users thought would enhance productivity:

a. A “send back” feature with full explanation and additional comments/links;

b. Ability to recall a promoted (forwarded) item (task);

c. A parallel processing feature with multiple receiving actors (note – this is a capability available in many other commercial workflow engines);

d. Additional reference library features such as quick links to maintenance documents (Maintenance Requirement Cards (MRCs), Maintenance Plans, drawings, reports, calculations, vendor information, etc.);

e. The ability to “mouse over” or click on the workflow image and display all information related to each node;

f. Instantaneous e-mail notification. (Note – HSIDE does provide this capability and this behavior is probably an artifact of the Electric Boat information environment due to firewalls, buffering, etc.);

g. The ability to attach all supporting information for each activity to the workflow node itself;

h. The ability to display progress scales for a given workflow to visually show “status at a glance;”

i. E-mail notifications that can be dynamically configurable by anyone in the process or management and that include detailed information on the entire action;

j. A file sharing capability similar to MicroSoft Sharepoint or Googledocs.

Electric Boat will use the lessons learned and benefits identified from exercising the workflows in the HSIDE prototype to assist in defining the OHIO Replacement HSI design support requirements for the Next Generation IPDE.

2.8.5 Supplemental Assessment

Due to the lack of data associated with HSI product development, it was not possible to assess HSIDE through comparison with legacy program data. Therefore, a more subjective analysis was planned, based on reports from the actual end users. To elicit this input, a survey was developed and promulgated to the end users who actually participated in the prototype evaluation. Questions were designed to reflect both the analyst and manager perspectives.

Question categories included information on system usability, utility in supporting product development, utility in data management, ability to enhance end user process awareness and understanding, and a general assessment. Questions were designed so that agreement with the statement indicated a positive contribution. Scores were totaled and reported as a percentage of total possible score.

The survey form is shown in Figure 37.

HSIDE Prototype Evaluation		
Role*:		
Criteria	**Rating (1-5)****	**Comments**
System Usability		
HSIDE "filters" make it easy to locate task-relevant data within large volume of available design resources		
HSIDE can be easily incorporated in user's daily routine		
HSIDE functional breakdown is a convenient method to organize end user tasking		
HSIDE requires minimal training to apply effectively in a production design environment		
HSIDE user interface is intuitive and easy to use		
HSIDE web-based interface is efficient mechanism for organizing, executing and managing HSI tasking		
HSIDE Utility - Product Development		
HSIDE 3D visualization is a useful capability		
HSIDE allows products to be generated in realistic schedule time frames		

HSIDE document management capabilities enhance user efficiency and productivity		
HSIDE document management capabilities enhance data storage, access and retrieval		
HSIDE document management capabilities explicitly illustrate relationship of source and dependent documents		
HSIDE enhances ability to perform HSI program planning early in design cycle		
HSIDE enhances access to supporting reference material		
HSIDE enhances accuracy of product analyses		
HSIDE enhances collaboration between end users and design/build/sustain team		
HSIDE enhances construction of experiential database that will enhance follow on programs		
HSIDE enhances documentation of HSI process execution		
HSIDE enhances end user productivity		
HSIDE enhances HSI analyst's ability to influence design		
HSIDE enhances HSI impact on product design		
HSIDE enhances HSI product configuration management		
HSIDE enhances HSI product life cycle support		
HSIDE enhances HSI product standardization		
HSIDE enhances management insight into HSI program execution and status		
HSIDE enhances re-use of products/resources		
HSIDE enhances rollover analyses of legacy systems and equipment		
HSIDE enhances user access to design data and resources		
HSIDE enhances user's ability to perform within program schedule constraints		
HSIDE High Driver database provides a useful functionality		
HSIDE INBOX functionality provides convenient means for notification of new tasking		
HSIDE Utility - Data / System Management		
HSIDE High Driver database provides a useful functionality		
HSIDE allows products to be generated in realistic schedule time frames		

HSIDE enhances ability to perform HSI program planning early in design cycle		
HSIDE enhances collaboration between end users and design/build/sustain team		
HSIDE enhances construction of experiential database that will enhance follow on programs		
HSIDE enhances documentation of HSI process execution		
HSIDE enhances HSI impact on product design		
HSIDE enhances HSI product configuration management		
HSIDE enhances HSI product life cycle support		
HSIDE enhances HSI product standardization		
HSIDE enhances management insight into HSI program execution and status		
HSIDE enhances management oversight of HSI processes		
HSIDE enhances management understanding of HSI program scope and status		
HSIDE enhances management's awareness of overall HSI workload		
HSIDE enhances re-use of products/resources		
HSIDE enhances rollover analyses of legacy systems and equipment		
HSIDE enhances user's ability to perform within program schedule constraints		
HSIDE INBOX functionality provides convenient means for notification of new tasking		
HSIDE increases end user accountability		
HSIDE workflows enhance process discipline and promote standardization of execution		
Use of HSIDE-like capabilities in Next Gen IPDE will provide efficiencies in the design process		
End User Process Awareness and Understanding		
HSIDE enhances understanding of difference between HSI and Life Cycle Support functions		
HSIDE enhances user awareness of assigned HSI tasking, workload and progress		
HSIDE enhances user understanding of their role in IPDE process		
HSIDE enhances user's understanding of assigned tasking		

HSIDE explicit representation of process information (e.g., workflows, BPMs) enhances user's understanding of expected tasking		
HSIDE general references provide overview and insight into overall HSI processes		
HSIDE inclusion of Use Case Analyses enhance analysts' understanding of expected product use		
HSIDE provides inherent value to the design process		
HSIDE should minimize downstream HSI design errors / HSI-based rework		
HSIDE workflows enhance understand of the relationship of activities/tasks and their order of execution		
General		
Incorporation of HSIDE-like capabilities will enhance future IPDE functionality		
User has direct experience developing or managing products in the HSIDE prototype environment		
Average Score:		
*A = Analyst/Engineer, S = Supervisor/Manager		
**5 = Strongly Agree		
4 = Agree		
3 = Neutral		
2 = Disagree		
1 = Strongly Disagree		
If Not Observed, Please Leave Blank		

Figure 37: Prototype User Evaluation Survey

Due to budget constraints, users were not able to complete this survey and the planned analysis was never carried out.

3 Findings and Discussion

The originally proposed HSIDE concept has been developed and evaluated and appears to be an effective means of defining, executing and managing an HSI program during a new ship design. It can increase efficiency, enhance accountability and oversight and provide a common, configuration managed resource for all associated HSI documents, products and objective quality evidence (OQE) used to validate a design from concept throughout the life cycle. Despite the promise of a HSIDE-like environment, there are many obstacles to successful integration of such environments in future ship design programs.

3.1 Lack of True System Engineering Perspective

During the execution of the HSIDE project, it was found that there is a profound lack of system engineering tools to help integrate HSI into modern ship design environments. Although there is great interest, desire and requirements to integrate HSI into new acquisition programs, there has been no concurrent effort to integrate HSI requirements and tools into production design environments. HSI processes, at least at the tactical or operational level, were, in general, found to be undefined and, despite development of high level HSI plans, the mechanisms to actually embed an integrated HSI approach into the design process were absent. Often, specific functional areas (e.g., ESOH at Electric Boat) did have well-developed and managed processes. However, these processes were usually previously developed as independent functions. There was lack of an overall organizing infrastructure to support their management and execution as part of an integrated, HSI-oriented, systems engineering approach.

In this regard, HSI has assumed a role similar to that of Life Cycle Support. Although it is recognized that HSI, when properly applied, can provide significant downstream total ownership cost savings, the driving need to reduce acquisition costs limits the opportunity to restructure programs to take advantage of those capabilities. Thus, many aspects of HSI are still initiated late in the design process where the available degrees of freedom to affect the design have been severely curtailed due to earlier design decisions. As such, HSI is seen less and less as an integrating mechanism that can provide global program benefit across a program and is viewed more and more as a simple extension of human factors engineering/interface design that can be used to locally improve specific functions.

The OHIO Replacement Program provides an opportunity to more fully integrate HSI into the design process of OHIO Replacement. However, due to the delayed OR Program implementation schedule, many of the early benefits attributed to HSI may be missed. The factors contributing to this potentially missed opportunity are discussed in more detail in the following sections.

3.2 Top Down Process versus Observed Execution

HSI has been structured very much as a top down, integrated, systems engineering approach (Virtual SYSCOM, 2005, SEA05H, 2008). This approach works well when assessed from a high level, programmatic perspective but there are many problems in

implementing HSI through an actual design program that can limit the expected benefits and effectiveness. Ship acquisition is a complex, long term and expensive process. While Department of Defense (DOD) Instruction 5000.2 process describes a well structured, basically linear approach to acquisition, a great deal of the technology, concept and even design work takes place outside of the framework of 5000.2 in independent, concurrent efforts. Many of the decisions made in this timeframe have major impacts on the program and on the effectiveness of HSI as applied to these programs (Skrmetti, 2006).

As an example, the OHIO Replacement Program is the U.S. Navy's newest submarine acquisition program. Having achieved Milestone A in January 2011, the program actually consists of bringing together several major, ongoing elements, each with a different history, constraints, development path and level of maturity. These elements include the missile compartment and strategic systems, the power plant, and the combat systems and command and control center.

The missile compartment, a major piece of the platform and the entire reason for being for this class of submarine, is being designed in conjunction with the Royal Navy as the Common Missile Compartment (CMC). Initial funding for the CMC was actually provided by the British Royal Navy as both the Royal Navy's Successor Program and the U.S. Navy's OHIO Replacement were to share a common design and, as initially structured, the Successor program led the US effort by several years. The initial contract to support concept studies and design was awarded under a foreign military sales agreement in December 2008, several years before the OHIO Replacement Program was officially established (Defense Industry Daily, July 11, 2011). This effort has been underway for several years and has generated a number of major constraints on the overall ship design which, at the current time, include missile size and number of tubes which drive hull diameter and the overall size of the missile compartment (O'Rourke, 2011, Thompson, 2011).

The size of the missile compartment is a critical component for habitability considerations as, in the original OHIO Class, all junior enlisted berthing and living areas were located in the missile compartment. Reducing the number of missiles will reduce the space available for crew living spaces unless a habitability module is included in the design. This problem could be exacerbated by the recent decision to introduce women into the submarine service as volumetric requirements to accommodate the crew may increase.

Propulsion plant design studies have also been going on for a number of years. The propulsion plant has to be sized to match the hydrodynamic requirements imposed by the diameter and length of the ship. However, because of the long lead time required to procure many of the major propulsion plant components and design and construct prototypes, the schedule and maturation of that design effort typically leads much of the rest of the ship and the engineering department is typically one of the major manpower drivers in submarine manning.

3.3 Legacy Systems / Push for Commonality

Another major factor impacting the effectiveness of the typically top down HSI approach is the desire to "rollover" legacy systems and equipment from previous submarine classes into new classes (Grossman, 2011). The desire for commonality in the combat systems, coupled with the evolutionary, incremental nature of the process used to upgrade submarine combat systems, and the desire to use common arrangement and equipment for the command and control center helps to greatly reduce the acquisition costs. It does, however, generate substantial constraints that limit the available degrees of freedom that could affect crew size or system design to enhance performance.

As an example, submarine combat systems are currently upgraded through an evolutionary process called the Advanced Processor Build (APB) Program. This program has a fixed schedule and process through which future enhancements are vetted, developed and tested. While extremely successful from a programmatic view, the constraints of the near-term, fixed schedule limits the enhancement to incremental upgrades rather than bolder redesigns that can make significant changes to the current systems architecture and interfaces and restricts the potential benefits that could be expected with a truly human-centric design.

This issue is closely related to the constraints generated through the traditional Navy acquisition system of Participating Acquisition Resource Managers (PARMs) / System-Based Acquisition. The Navy typically assigns system design and acquisition functions to a PARM. Examples are SONAR and the combat system. PARMs are focused on specific system functionality, performance and cost and are not typically concerned with interactivity across systems. This system level focus often precludes top down design and can result in less than optimal manning at the platform level. It is highly unlikely that the PARM organization/structure will be changed in the near future, unless a strong Ship Acquisition Program/Project Manager (SHAPM) is established. HSI practitioners must, however, be aware of this constraint and work closely with the respective program office to accommodate.

3.4 Manning for Design vs. Design for Manning

Manning is another area that is highly constrained by the acquisition approach. Manning optimization, from an HSI perspective, is considered a top down process. In reality, manning assessment is typically a rollover of existing class manning requirements, based on historical experience, modified to reflect technology insertions or new mission requirements. The reasons for this are numerous and, for the OHIO Replacement Program, include the lack of time or funding to develop and validate a fully new manning concept, the need to maintain commonality across platforms, the evolutionary nature of the APB process and the PARM acquisition structure and, most importantly, the need to minimize the risks associated with the deployment and availability of a key strategic asset. Therefore, from an HSI perspective, we are actually constrained to "optimize" or, through analysis and modeling, validate an evolutionary manning model. Even DDG-1000, which has had in place a Key Performance Parameter (KPP) for manpower since its original inception, has significantly evolved its original manning estimates as the ship design matured (Galdorisi and Truver, 2011). Despite this, DDG-1000 is probably the

closest we have come to actually designing a ship to meet our manpower goals. We do not actually design a ship for optimal manning. We optimize manning as part of the larger, and highly constrained, ship design process.

3.5 Lack of Baseline Cost and Cost/Benefit Data to Support HSI Decisions in New Programs

There is also a lack of quantitative budgetary data to support the inclusion of HSI in a new program, both from a pure cost perspective and from a cost/benefit perspective. As noted in Liu (2010), "Despite the prominence given to HSI in a number of policy documents, the National Academies, in a 2007 report on HSI, identified "a lack of commitment by funders and program managers to assign priority to [HSI]" as well as "a lack of effective communication between system engineers and human-system domain experts" to be challenges inhibiting the practice of HSI (Pew and Mavor 2007). As part of its conclusions, the report recommended further research in "estimating the size of the HSI development effort" as a means of achieving "full integration of human systems and systems engineering" (Pew and Mavor 2007)."

The HSI community has relied on DDG-1000 and the Littoral Combat Ship (LCS) as the "poster programs" to demonstrate the benefits of HSI. These programs are both highly visible and have shown success in bringing HSI issues to the forefront of ship design. There are, however, several major problems with using these ships as an example of how HSI should be implemented in future programs. DDG-1000 is the end result of a nearly 15 year design effort. It has undergone several major changes in program scope (DD-21, DD(X) and DDG-1000) but has yet to put a ship of this class to sea to validate HSI design effectiveness. In most programs, schedule timeframes, as experienced in DDG-1000, are not available and time frames are much more compressed.

Other mitigating circumstances have been noted in the LCS. LCS was structured and acquired as a research and development project, outside of the typical mainstream shipbuilding acquisition process and with 3 main program offices playing a role in the overall LCS design. Although there are already several hulls at sea, the LCS Program Office was just officially established in July 2011. There are two very different variants, both based on commercial hull forms or technologies. The ships have been designed and placed in service with none of the logistics tail usually associated with a combat platform in place. As an example, there is still no maintenance strategy for LCS and serious questions are unanswered in regard to personnel and training (GAO, 2010).

Because of the lack of a solid baseline with which to demonstrate the true benefit of HSI, practitioners are still required to prove the worth of HSI in new programs. Even though all new programs are required to incorporate HSI into their programs, "how much HSI is needed and what will it cost me?" are still key questions that need to be answered and answered very early in the program. To ensure a "critical mass" of HSI analysis is included in a new program, practitioners must be able to quickly and accurately generate cost/benefit assessments to justify inclusion of specific tasking in a program budget.

3.6 HSI Functions Overlap those of Life Cycle Support

The development of integrated product data environments has enabled the systems engineering methods used in modern product design. HSIDE simply extends this paradigm of "operationalizing" systems engineering to the human systems integration arena. HSI has been approached as something related to, but distinctly different from, both traditional design and life cycle support. This has caused a great deal of confusion among customers, designers and the life cycle support community itself as, in an actual design environment, many HSI functions (e.g., maintainability, safety, training) are often (and have been historically) performed by life cycle professionals.

3.7 Recommendations

3.7.1 New Design Approaches

The constraints generated by the inclusion of legacy systems and the push for commonality are real issues and must be addressed. The HSI community must develop novel methods of functional integration and concepts of operation that can incorporate these legacy systems into new operational paradigms that can reduce costs and/or increase performance. As an example, Rite-Solutions' Combat System of the Future development effort provides an integrating layer over the existing PARM-based combat system functional areas to support a new concept of operations for future submarine command and control without a need to redesign the supporting subsystems. Similar integrating concepts, such as those enabled by integrated platform management systems, are necessary to address hull, mechanical and electrical (HM&E) operations of the platform as a whole.

3.7.2 HSI Cost/Benefit Assessment

HSI practitioners must be able to respond quickly and accurately with requests from program managers as to the cost of incorporating HSI into their programs. They must be able to estimate the expected scope of an HSI program and be able to accurately track and monitor those costs during program execution. This will require methods to define program deliverables to a level of discreteness that will allow realistic estimation of development costs and cost/tradeoff studies. The HSIDE project has developed methods to define a program scope based on a given level of risk. This work needs to be combined with realistic cost estimations to be able to provide program managers with the tools they need to make informed decisions about the level of HSI that will be integrated into their programs.

3.7.3 Expanded Systems Engineering Perspective

It is apparent that, as part of true systems engineering approach, HSI can act as a bridge between the traditional acquisition-oriented design perspective, which is heavily focused on system functionality, equipment selection, arrangements and production and the broader life cycle support perspective which is focused on availability, sustainment and total ownership cost. In the world of fleet ballistic missile (FBM) submarines such as the OHIO Replacement, these life cycle aspects are paramount to fulfilling the strategic mission. A broader perspective is required and HSI can help provide this perspective.

The systemic integration of the HSI and life cycle support environments with the traditional design environment could ultimately provide significant benefit to the Navy. It extends the reach and influence of the systems engineering process across the entire life cycle of the ship, extending the design/build approach currently used in submarine acquisition to one of design/build/sustain, where human performance and life cycle support issues are brought to the forefront immediately during the concept development and design phases and are incorporated as integral aspects of the design. HSIDE-like systems are simply the next step in the development of a highly integrated systems engineering environment that cover all aspects of a program.

4 The Future of HSIDE

HSIDE is currently being used as a visual specification to aid Electric Boat in refining requirements for the HSI functionality of the Next Generation Integrated Product Data Environment (IPDE). PMS397 (OHIO Replacement Program Office) has signed a Level A Technology Transition Agreement to support the transition of HSIDE concepts and knowledge products to influence the Next Generation IPDE.

In addition to use in submarine design, HSIDE provides the ability to support other naval ship design programs, but particularly the DDG-51 Restart. Since the original DDG-51 design preceded 3D, computer-based design systems, HSIDE can act as a gateway between the legacy design and a fully modern 3D model-based design environment providing the ability to capture, integrate and manage the various data types required to successfully execute such a transitional design and support the resulting ships throughout their life cycle.

Finally, HSIDE has demonstrated the benefit of constructing a functionally-oriented, web-based front end to a complex (in this case, PLM-based) back end system. HSIDE "operationalizes" the systems engineering approach to design to a level that has not been seen with other commercial or special application systems. This approach provides benefit not only for HSI-related work but can be expanded to cover all of life cycle support functionality and may even be extended to the full scope of systems engineering activities. Rite-Solutions will continue to pursue opportunities to apply HSIDE to a wide range of complex design programs in both the government and private sectors.

5 REFERENCES

CMC Program to Define Future SSBN Launchers for UK, USA (2011). Defense Industry Daily, July 11, 2011.

Committee on Human-Systems Design Support for Changing Technology, & Richard W. Pew and Anne S. Mavor (Editors). (2007). *Human-system integration in the system development process: A new look*. Washington, DC: National Academy Press.

Galdorisi, G. V., Truver, S. C. (2011) *From Minimal to Optimal.* Proceedings. US Naval Institute. July 2011.

GAO (2010). *Navy Needs to Reassess Its Metrics and Assumptions for Ship Crewing Requirements and Training*. GAO-10-592. United States Government Accountability Office, June 2010

Grossman, E., M. (2011). *Future U.S. Nuclear-Armed Vessel to Use Attack-Submarine Technology.* Global Security Newswire, Thursday Feb. 24, 2011.

Koopmans, T. C. and Beckmann, M. (1957). *Assignment Problems in the Location of Economic Activities*. Econometrica, Vol. 25, No. 1 (Jan., 1957), 53-76.

Liu, K.K., (2010). Cost *Estimation of Human Systems Integration*. Master's Thesis, Engineering Systems Division, Massachusetts Institute of Technology, June 2010.

O'Rourke, R. (2011). Navy SSBN(X) *Ballistic Missile Submarine Program: Background and Issues for Congress.* Congressional Research Service, 7-5700. April 22, 2011.

Pina, P.E., Donmez, B. and Cummings, M.L. (2008). *Selecting Metrics to Evaluate Human Supervisory Control Applications,* MIT Humans and Automations Laboratory, Cambridge, MA HAL2008-04, 2008.

Rite-Solutions (2009). *Combat System of the Future, Phase II SBIR N05-149 Final Report*. Prepared for, and issued by, NAVSEA PMS425, April 29, 2009

Rite-Solutions (2010). List Of Measures Of Effectiveness/ Measures Of Performance (MOEs/MOPs) To Be Used In Design Evaluation. Prepared by Rite-Solutions for Office of Naval Research, Contract No: N0004-08-C-0327, October 31, 2010.

Skrmetti, T. (2006). Integrating HSI in Submarine Design. Presented at Humans and Automation Conference, Massachusetts Institute of Technology, Cambridge, MA, January, 2006.

Skrmetti, T., Olivier, D., Ferguson, J., Jenkins, D., Skrmetti, S., Levesque, M., Lame, M.

(2010*). Human Systems Integration Design Environment (HSIDE) Phase I Project Report*; Office of Naval Research. Contract No: N0004-08-C-0327, CLIN 0001, Data Item No. A003. February 25, 2010.

Skrmetti, T., et al (2009). *Human Systems Integration Design Environment (HSIDE) HSI Tool Evaluation Study.* Prepared for the Office of Naval Research, Contract No: N0004-08-C-0327, June 17, 2009

Skrmetti, T. J. (2011). *Lessons Learned and Real World Compromises Identified When Operationalizing HSI in a Ship Design Environment*. Presented at the 2011 ASNE Human Systems Integration Conference, Vienna, VA. October 25-27, 2011

Thompson, L. (2011). *The Submarine That Might Save America.* Forbes, June 20, 2011